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FULL-SCALE TRIALS OF LIFEBOAT EVACUATION SYSTEMS

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Since the accepted measures in the industry are a blend of metric and imperial, both metric and imperial measures are used in this report.

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16. Abstract

The ability to collect full-scale lifeboat launch data from offshore installations is critical. A research program developed and used a data acquisition system to capture deployment and manoeuvring performance data from a full-scale, twin-falls davit-launched lifeboat for the purpose of correlation with model-scale experimental results. The aim of the program was to provide objective, reliable data concerning particular aspects of evacuation performance that can be used by designers, regulators, and others in their decision-making.

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16. Résumé

Il est essentiel de pouvoir recueillir des données concernant la mise à l'eau de radeaux de sauvetage en vraie grandeur depuis des plates-formes en mer. Un programme de recherche a vu au développement et à la mise en œuvre d'un système de collecte de données qui permet de recueillir les données sur le déploiement et la manœuvre d'un radeau de sauvetage en vraie grandeur mis à l'eau par un bossoir à treuil double, aux fins de corréler ces données avec les résultats d'essais sur maquette. Le but du programme était de réunir des données objectives et fiables concernant des aspects particuliers de la mise à l'eau, sur lesquelles les concepteurs, les organismes de réglementation et les autres groupes intéressés pourront appuyer leurs décisions.

17. Mots clés Essai en vraie grandeur, essai sur maquette, corrélation, performance, facteur de sécurité critique, bossoir à treuil double, déplacement et orientation privilégiés (PrOD), tangon PrOD, embarcation de sauvetage motorisée entièrement fermée, ESMEF, lestage, délestage, conditions de charge	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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Special thanks are offered to the undergraduate engineering students who made great contributions to the project team.

EXECUTIVE SUMMARY

This project involved the development and use of a data acquisition system to capture deployment and manoeuvring performance data from full-scale, twin-falls davit-launched lifeboats for the purpose of correlation with model-scale experimental results.

Full-scale trials were performed at the Fisheries and Marine Institute of Memorial University (MI), Offshore Safety and Survival Centre (OSSC), in September 2002. This training facility's conventional twin-falls davit launch system, equipped with a Preferred Orientation and Displacement (PrOD) boom, was used to deploy a Totally Enclosed Motor Propelled Survival Craft (TEMPSC) from a fixed platform in calm conditions. Data was collected during TEMPSC deployment and operation in each of several lifeboat and launch system configurations.

Methods were developed that could be used for lifeboat performance data collection onboard offshore installations. As typical lifeboat launching systems can only recover the boat in light condition (launching crew only), particular attention was paid to the means of ballasting and de-ballasting the boat. Lifeboat loading was changed to deploy the boat in heavy and light conditions, both with and without the use of PrOD. Issues relating to aborting the launch with the boat in heavy condition were investigated. The TEMPSC was also deployed without engine power, using only PrOD assistance to help the lifeboat clear the splashdown area. The lifeboat's thrust, acceleration and turning characteristics were evaluated.

Critical factor-of-safety issues were identified relating to shock loads experienced when aborting a lifeboat launch.

The ability to collect full-scale lifeboat launch data from offshore installations was demonstrated.

SOMMAIRE

Ce projet a consisté à développer et mettre en œuvre un système de collecte de données qui permet de recueillir des données sur le déploiement et la manœuvre d'un radeau de sauvetage en vraie grandeur mis à l'eau par un bossoir à treuil double, aux fins de corréler ces données avec les résultats d'essais sur maquette.

Les essais en vraie grandeur ont eu lieu à l'Offshore Safety and Survival Centre (OSSC) du Fisheries and Marine Institute of Memorial University, en septembre 2002. Le dispositif de mise à l'eau à treuil double classique de ce centre de formation, équipé d'un tangon PrOD (pour Preferred Orientation and Displacement), a été utilisé pour déployer une embarcation de sauvetage motorisée entièrement fermée (ESMEF) à partir d'une plate-forme fixe, dans des conditions calmes. Des données ont été colligées sur le déploiement et la manœuvre de l'ESMEF dans diverses configurations du radeau et du dispositif de mise à l'eau.

Des méthodes ont été élaborées pour permettre la collecte de données sur les performances des radeaux de sauvetage à bord de plates-formes en mer. Comme les dispositifs de mise à l'eau types ne peuvent récupérer le radeau qu'à l'état lège (équipe de mise à l'eau seulement), une attention particulière a été apportée à des moyens de lestage et de délestage du radeau. Ainsi, on modifiait la charge du radeau pour déployer celui-ci à l'état lège et lesté, avec et sans tangon PrOD. On a aussi examiné les problèmes reliés à l'interruption de la mise à l'eau avec le radeau à l'état lesté. L'ESMEF a aussi été déployée sans moteur : seul le tangon PrOD était alors utilisé pour amener le radeau à l'extérieur de la zone d'amerrissage. Les caractéristiques de poussée, d'accélération et de rotation du radeau de sauvetage ont été évaluées.

Les facteurs de sécurité critiques reliés aux charges d'impact associées à l'interruption d'une mise à l'eau ont été cernés.

Finalement, la capacité de colliger des données concernant la mise à l'eau de radeaux de sauvetage en vraie grandeur depuis des plates-formes en mer a été démontrée.

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GLOSSARY

A/D	Analog/Digital
BOA	Beam Overall
CD-R	Compact Disc-Re-Writable
CG	Centre of Gravity
CSV	Comma Separated Values
DGPS	Differential Global Positioning System
DV	Digital Video
EER	Escape Evacuation and Rescue
FOS	Factor of Safety
GEDAP	Generalized Experiment Control and Data Acquisition Package
GM	Metacentric Height
GPS	Global Positioning System
GRP	Glass Reinforced Plastic
IEEE	Institute of Electrical and Electronics Engineers
IMD	Institute for Marine Dynamics (now Institute for Ocean Technology)
IMO	International Maritime Organization
IOT	Institute for Ocean Technology (formally Institute for Marine Dynamics)
JRPA	Joint Research Project Agreement
LAN	Local Area Network
LOA	Length Overall
LSA	Life Saving Appliance
MI	Marine Institute
MPD	Metres per degree
NTSC	National Television System Committee
OL	Offshore Lifeboat
ORD	Out Rigger Davit
OSSC	Offshore Safety and Survival Centre
PC	Portable computer
PDOP	Position Dilution of Precision
PrOD	Preferred Orientation and Displacement
SOLAS	Safety of Life at Sea
SWL	Safe Working Load
TEMPSC	Totally Enclosed Motor Propelled Survival Craft

1.0 INTRODUCTION

This work was undertaken in support of the Joint Research Project Agreement (JRPA) on Offshore Evacuation Systems. Particular focus was placed on the evacuation portion of the Escape Evacuation and Rescue (EER) process.

As the offshore oil and gas industry and its regulators increasingly move away from prescriptive rules and toward a performance-based regulatory regime, clearly defined performance criteria and the means to measure performance become necessary for assessing risk and managing safety on offshore installations.

A performance-based approach to providing the necessary evacuation capability for offshore installations requires the systematic development of evacuation performance standards and the implementation of a program of verification to confirm that the required performance is achievable under the conditions in which the evacuation systems are expected to operate. Duty holders must quantify evacuation system performance and demonstrate that evacuation systems deliver good prospects for survival in all credible emergency scenarios.

To establish confidence in evacuation system performance, duty holders may conduct full-scale trials that are representative of credible emergencies. It is anticipated that such trial launches can be safely conducted in weather states above calm but risk control requirements will likely limit testing in more severe weather.

Alternatively, physical model experiments can be used to investigate evacuation performance and collect data in simulated weather conditions where the risk is prohibitive if done with full-scale manned equipment. Furthermore, model trials can be repeated under controlled conditions to generate statistically significant data. However, to ensure data reliability, model test results must be correlated with data collected at full-scale. The acquired performance data can then be compared to the weather limits expected in the area of operation and realistic performance objectives established for those conditions.

The intent of this project was to develop and demonstrate the capability for full-scale data collection at low environmental conditions and to provide full-scale data for comparison with experimental model-scale results acquired at equivalent environmental conditions. This comparison would then give some support to the application of model-scale performance results for extreme weather limits to the assessment of full-scale evacuation system performance at those extremes. Furthermore, the suitability of the data acquisition system was to be assessed for possible future full-scale test launch use with a remotely operated TEMPSC in more extreme weather conditions.

2.0 PROJECT OBJECTIVES

The broad objectives of the project were to develop data collection capability for the performance assessment of full-scale evacuation systems and to demonstrate proof-of-concept for such performance assessment by collecting data using a lifeboat and launching system located at an emergency response training facility.

The objectives above were met by completion of the following tasks:
1. Identify the performance measures relevant to lifeboat launch
2. Select a full-scale evacuation system suitable for proof-of-concept use
3. Determine the data collection requirements for performance measurement
4. Develop the matrix for the test program launches
5. Develop, install and test the data acquisition system
6. Conduct test matrix deployments
7. Evaluate the performance of the data collection system

3.0 EVACUATION PERFORMANCE MEASURES

A set of 12 evacuation performance measures was selected for use in the full-scale trials. These measures were developed experimentally by Simões Ré and Veitch [1] and have evolved further [2, 3]. The measures were developed and used in scale-model testing and were designed to quantify the performance of a twin-falls davit launched TEMPSC deployed from a stationary platform in simulated emergency evacuation conditions. These measures form the basis for a quantitative analysis of the data collected in those physical model tests.

Using these 12 evacuation performance measures for the full-scale deployment trials supports the comparison with model-scale test results. However, it is recognized that with full-scale testing conducted in calm conditions, some of these performance measures are of minor significance, as there is no weather challenge to TEMPSC performance. Even so, the data collected should be directly comparable to model-scale test results obtained in corresponding calm weather deployments. Similarly, all the data collection instrumentation should be utilized sufficiently to demonstrate proof-of-concept for this approach to the assessment of full-scale evacuation system performance and to indicate the usefulness of extending this approach to full-scale tests at weather states above calm.

The procedures for the collection and analysis of full-scale trials deployment data are therefore explained with reference to these twelve evacuation performance measures. Some of the measures have to be considered in combination, whereas others can be interpreted alone. The performance measures are presented in Table 3.1; a brief description is given below.

Table 3.1 TEMPSC Evacuation Performance Measures

Item	Description of Performance Measure
1	Elapsed time from launch to splash-down
2	Elapsed time from splash-down to splash-down border
3	Elapsed time from splash-down to clear rescue zone border
4	Avoidance of collisions during lowering
5	Avoidance of collisions after launch
6	Accuracy of launch position relative to target point
7	Extent of setback
8	Path length from splash-down to splash-down border
9	Path length from splash-down to clear rescue zone border
10	Accelerations during lowering
11	Accelerations during sail-away
12	Seaworthiness criteria, progressive setback

The measurement of evacuation performance is supported by defining several evacuation zones. Figure 3.1 illustrates these zones.

The splash-down zone is centred on the target launch point and is circumscribed by a boundary that is described as the area required by the TEMPSC to begin making way after launch. Accordingly, the splash-down boundary is not a fixed size, but rather is expected to be bigger in rougher conditions and smaller in more benign conditions. For this project, a size was set somewhat arbitrarily at 15 m radius.

A rescue zone is identified to seaward of the splash-down zone. The boundary of the rescue zone is defined as the minimum distance from the installation that is considered safe for rescue operations. This distance was set at 25 m for this project.

An exclusion zone is identified on the platform side of the splash-down zone and the lifeboat should not enter this zone at or after splash-down. The boundary of the exclusion zone would therefore encompass all collision hazards and be large enough to accommodate launching with the installation in the damaged condition. In previous work, the exclusion zone was typically established such that its boundary was tangential to the splash-down zone. However, the training facility launching system only provided only limited clearance between the launch platform and the stern of the TEMPSC. Therefore, for this project, the exclusion zone boundary is not the normal tangent to the splash-down zone boundary but instead truncates the splash-down zone at a distance of 1.5 m astern of the lifeboat's stowed position.

A clearing zone is identified as the area between the exclusion and rescue zone boundaries. The clearing zone includes the splash-down zone.

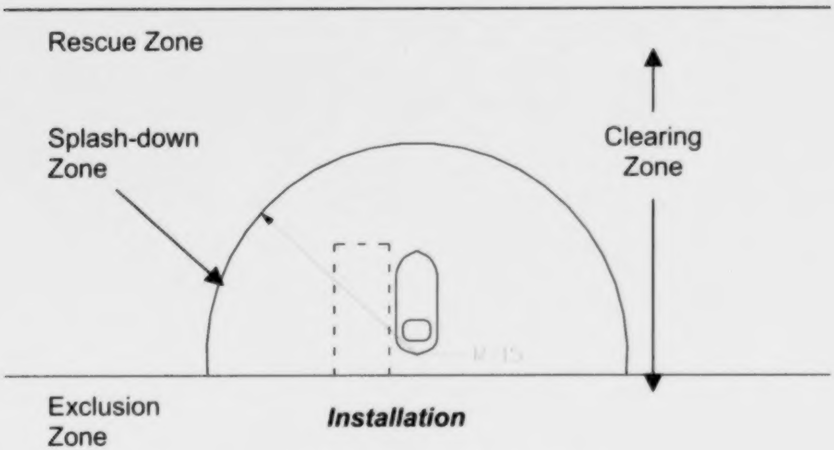


Figure 3.1 Evacuation Zones

The splash-down, exclusion and rescue zones, in practice, would have to be sized and defined to accommodate the specific configuration of each offshore installation, the location of the lifeboat stations on the installation, the prevailing environmental conditions and the practical limits of the evacuation system. It follows that the times for transiting these evacuation zones define three phases of the evacuation and are simple indicators of performance.

The first performance measure listed in Table 3.1 is the time required for the lowering phase or from start of lowering to splash-down. This lowering time is not just a simple function of the automated control of winch deployment speed because the operator may introduce delays. A lowering delay could be inadvertent or deliberate so as to "time" the lowering to avoid hazards such as flotsam or unfavorable approaching wave conditions. If "timed", the lowering might be prolonged but still not degrade evacuation performance.

The second performance measure is the time required for the TEMPSC to vacate the splash-down zone. This reflects the time it takes for the lifeboat to be in control and start making way after splash-down.

The third performance measure is the time required for the TEMPSC to clear to the rescue zone after splash-down. This time covers the entire sail-away phase of evacuation and is the total time required to exit the clearing zone.

The fourth performance measure deals with collisions that may occur between the TEMPSC and the installation during lowering. Such collisions can result in immediate injury to lifeboat occupants and/or damage to the lifeboat itself and thereby impair evacuation performance.

The fifth performance measure flags collision after splash-down. Such collision would occur if the TEMPSC were forced by weather or inadvertently manoeuvred into the exclusion zone and impacts the installation.

In the case of a lifeboat station, the point directly below the TEMPSC in its stowed position is known as the launch target point. Since it is a target, the lifeboat's launch accuracy is determined by measuring the distance between the actual splash-down point and the target. This distance indicates the degree of control that the launch system has over the deployment of the boat during lowering and is the sixth performance measure.

After splash-down, some time may elapse before the TEMPSC can gather way. Wave encounters during this initial period can set the lifeboat back toward the installation and the exclusion zone and away from the goal of the rescue zone. This setback distance is the seventh performance measure. Setback is illustrated in Figure 3.2.

The eighth and ninth performance measures are the path lengths traversed by the TEMPSC during sail-away that correspond to the transit times evaluated in performance measures two and three. These measures indicate the directional control of the lifeboat and how far it deviates from an ideal straight path as it clears both the splash-down and rescue zones.

The tenth and eleventh performance measures are the accelerations of the TEMPSC during lowering and sail-away. During lowering, the maximum z-acceleration is of interest as an indicator of the risk to boat occupants that might result from any impact events. During sail-away, accelerations are important when assessing both the potential for harm to boat occupants and the performance of the TEMPSC in rough weather.

If the TEMPSC is progressively set back by successive wave encounters and does not effectively make headway, this marks a weather limit of the lifeboat performance. This progressive setback is the twelfth performance measure. This measure is a significant indicator of the seaworthiness of the lifeboat as evacuation systems should not be expected to function in weather conditions that go beyond the point at which progressive setback causes danger zone incursions or collisions. Other similar limits could be set for capsizing and excessive motions.

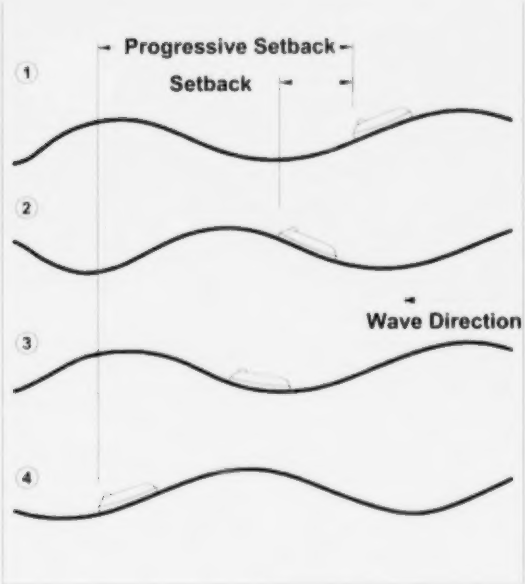


Figure 3.2 Setback

All 12 evacuation performance measures above are important in extreme weather conditions. However, it is accepted that when conditions tend toward calm, the weather challenge is reduced and less significant information is provided by performance measures relating to collisions during or after launch, missed target distance, setback distance, path lengths to the splash-down zone and rescue zone borders, and progressive setback.

3.1 Other Performance Indicators

Additional testing is necessary to complement the evacuation-specific measures described above and more fully investigate TEMPSC and launching system performance. These additional measures may be of use to understand the performance of system components in normal use or after sustaining damage or subsequent to operator error. Therefore, the measures listed in Table 3.2 and briefly explained below are not evaluated during calm weather evacuation trials but are investigated separately.

The dynamic or "shock" loads on the lifeboat fall wires are of interest in relation to the required minimum factor of safety (FOS). In the static condition, with the fully loaded TEMPSC suspended on the boat falls, simple checks can verify that the required minimum FOS of six is maintained. However, in the event of an aborted launch, where TEMPSC lowering is stopped when the winch brake is applied, the dynamic loads might exceed the maximums allowed by the factor of safety. This

measure also addresses the ability of the winch brake to meet the requirement that it be able to stop the descent of the boat and hold it securely.

Table 3.2 TEMPSC Additional Performance Measures

Item	Description of Performance Measure
1	Dynamic load forces on lifeboat fall wires
2	TEMPSC zero to six knot speed
3	TEMPSC turning characteristics
4	TEMPSC bollard pull
5	TEMPSC transverse metacentric height
6	TEMPSC heave, pitch and roll periods

The TEMPSC's zero to six knot speed (in calm conditions) is a measure of the ability of the boat to accelerate from a standing start. Although this measure may indicate the lifeboat's ability to avoid or overcome setback and clear the installation, it is not specific to the configuration of the installation or launching system and may therefore be a useful reference for TEMPSC comparisons.

The TEMPSC's turning characteristics are of interest as a measure of the boat's manoeuvrability that complements the path length measures described above. Systematic investigation of turning ability is necessary because evacuation trials, with the goal of deploying and operating the lifeboat to exit the clearing zone as efficiently as possible, may only provide a good indication of coursekeeping ability. We therefore need an additional measure to inform us about the boat's ability to avoid collisions or be manoeuvred through a required change of course. Turning ability may be a useful reference for TEMPSC comparisons that is independent of the launching system.

The bollard pull of the lifeboat is an indicator of the thrust available for the TEMPSC to get underway and start to manoeuvre clear of the installation. The bollard pull is also of interest as a measure of the boat's ability to tow a loaded survival craft.

The transverse metacentric height (GM) of the TEMPSC can be determined by conducting an inclining experiment and is of interest as a measure of the lifeboat's initial stability.

The natural heave, pitch and roll periods of the TEMPSC can be determined by conducting heave, pitch and roll decay experiments and are of interest as a measure of the lifeboat's "seakindliness".

4.0 SELECTION OF EVACUATION SYSTEM

The Fisheries and Marine Institute of Memorial University (MI), Offshore Safety and Survival Centre (OSSC), Southside Marine Base, was selected as the location for the full-scale trials. This training and research facility operates a variety of survival craft and launching systems and, for use in launching trials, offered a TEMPSC deployable with a fixed offshore-type twin-falls davit system that was fitted with a PrOD boom. This system was set up for offshore training use and was configured to represent a typical conventional lifeboat evacuation system appropriate to a bottom-founded offshore installation.

The TEMPSC was a standard Umoe Schat-Harding type "24 MCB T" with a capacity of 50 persons. This lifeboat has a LOA of 7.46 m and BOA of 2.9 m and fully equipped has a nominal weight of 3850 kg. Fully loaded, the boat would weigh 7600 kg. This lifeboat was powered with a Saab "L3 139 LB" engine rated at 29 hp, driving a fixed three-bladed propeller, 17 in. diameter x 16 in. pitch, with steering nozzle and providing sufficient power for the fully loaded boat to achieve the International Maritime Organization (IMO) Safety of Life at Sea Convention (SOLAS) minimum required speed of 6 kn in calm water. The lifeboat was fitted with a pair of TOR "Twin Safe" on-load release hooks each with a safe working load (SWL) rating of 6000 kg.

The lifeboat was deployed with a Umoe Schat-Harding ORD conventional twin-falls davit mounted on a steel platform with a deck height approximately 8 m above the high waterline. The davit was positioned on this platform such that the boat was perpendicular to the platform side and would therefore launch in the standard "bow-out" orientation. The davit arms were fixed in position and rated with a SWL on the inboard (aft) davit arm of 4000 kg and on the outboard (fwd) arm of 3750 kg. The davit was fitted with an "electro-hydraulic" winch, type W120 – OL (offshore lifeboat), with an SWL rating of 120 kN (≈12200 kg) and supplied with suitable braking and power to lower and raise the TEMPSC at the required SOLAS standard speeds.

The lifeboat, davit and winch were constructed and tested to meet the appropriate SOLAS standards that were current in 2000. The standards for life-saving appliances required by SOLAS Chapter III are provided in the International Life-Saving Appliance (LSA) Code [4], which specifically addresses load-rated components in section 6.1.1.6, where it states that a minimum factor of safety of 6 shall apply to all falls, suspension chains, links and blocks.

The davit and winch were supplemented with a Umoe Schat-Harding Preferred Orientation and Displacement (PrOD) system of the type approved by Transport Canada for use on offshore units. The principle component of PrOD is a flexible glass reinforced plastic (GRP) boom with a base pivoted on the platform and normally held in position hydraulically between 30° and 40° to the horizontal.

The free tip of the boom points directly away from the installation in the escape direction and from there a tag line runs to a release hook at the bow of the davit launched lifeboat. As the lifeboat is lowered, the tag line is tightened and the boom is pulled downward. This rotation of the boom charges a hydraulic accumulator and the increasing resistance of the boom to motion creates tension in the tag line that orients the boat during its descent to point away from the platform. Once the lifeboat reaches the water, the falls are released and the tag line continues to pull the boat away from the installation as the energy stored in the accumulator raises the boom to its original position and sustains tag line tension. This action assists forward propulsion and reduces the probability that the lifeboat will be washed back into the platform in bad weather conditions. Once the bow of the lifeboat is directly under the tip of the PrOD boom, the tag line automatically releases, by which time the lifeboat's engine should already be at full thrust. In addition, should the lifeboat release mechanism not function as designed, the tag line may (in low weather conditions) hold the lifeboat clear of the installation until the problem has been resolved and the boat is released.

The manufacturer states that its PrOD system has been approved by the Canadian Coast Guard for fitting on Canadian offshore units subject to a full load condition test carried out on each.

The PrOD system components are designed and constructed such that a standard PrOD boom length is used to accommodate varying TEMPSC launch heights and orientations. The necessary performance for a specific installation is then achieved by adjusting the mounting height and location of the PrOD boom base, the length of the tag line, the "park angle" of the boom and the nitrogen pre-charge pressure in the hydraulic accumulator. With the 8 m launch height at the OSSC being much lower than that of a working offshore installation, effective functioning required that the PrOD boom be set at a high park angle, be fitted with a short tag line and use an increased nitrogen pre-charge pressure. This combination of measures allowed sufficient energy to be stored to provide lifeboat tow-away in spite of the short PrOD system stroke obtained from the reduced lifeboat launch height.

The 8 m platform with 50 person TEMPSC and PrOD-equipped launching system was positioned on the wharf apron at Pier 25 in St. John's harbour. The wharf edge ran approximately northeast to southwest and the lifeboat was deployed such the boat launched pointing approximately northwest.

Selected pictures of the training facility lifeboat and launching system are included in Appendix A.

5.0 INSTRUMENTATION

The instrumentation used for the full-scale testing consisted of the following:

1. Load (25 t) cell used with crane and lifting arrangement to determine mass of lifeboat
2. Load cell mounted to the tag line attachment at the tip of the PrOD boom to monitor tag-line loads during lifeboat deployment
3. Load cell mounted in tow line arrangement to monitor loads during bollard pull tests
4. Inclinometer mounted to the PrOD boom to monitor boom angle during lifeboat deployment
5. Three accelerometers mounted on the launch platform to record platform longitudinal, lateral and vertical accelerations during lifeboat deployment
6. Magnetic switch mounted on winch brake release handle to monitor winch brake release event
7. One capacitance wave probe positioned to capture wave environment data at the lifeboat splashdown area
8. One yo-yo pot positioned to record winch drum rotation as a measure of payout
9. Anemometer mounted above the 8 m platform to record wind speed and direction
10. Shore side PC for shore side data collection, signal and power boards, mini-DV recorders
11. One motion pack mounted at the CG of the lifeboat to capture 6° of motion information for the lifeboat
12. Magnetic switch assembly mounted near propeller shaft to monitor shaft rpm (not working)
13. One yo-yo pot mounted close to the lifeboat rudder post to monitor rudder post rotation to determine rudder angle
14. Two accelerometers, one mounted in each end of the lifeboat to monitor stern and bow vertical accelerations
15. Magnetic switch mounted on hydrostatic interlock indicator to monitor water entry (interlock open) status
16. Magnetic switch mounted on release gear handle to monitor release gear opening event
17. Two inclinometers mounted in the stern of the lifeboat to monitor pitch and roll
18. Trimble DSM 212 DGPS receiver mounted in lifeboat to provide time, latitude and longitude, course over ground and speed over ground data
19. Lifeboat PC, signal and power boards, 802.11b wireless network

Selected pictures of instrumentation equipment are provided in Appendix A.

5.1 Calibrations

All analog sensors were calibrated before the start of the experiments. The response of the sensor to a set of exciting loads was measured and a straight line fitted through the data points by means of a least squares technique.

The line is defined by two constants A and B, which relate the integer analog-to-digital (A/D) converter reading (counts) to the physical quantities being measured according to the following linear transformation:

$$X = A(k) \times (M - B(k)) \tag{1}$$

where:

X = physical value in physical units,
M = integer A/D converter reading,
A(k) = sensitivity of the sensor connected to the A/D channel k in physical units per count, and
B(k) = zero offset of the sensor connected to A/D channel k in counts.

The purpose of the calculation is to determine the constants A(k) and B(k), and to ensure that the sensor functions properly and has a linear response. The constant A(k) also represents the digital resolution of the measurement. All calibrations are provided in Appendix B.

5.2 Data Acquisition

The data acquisition system used in the full-scale testing employed two computers, one on the “shore side” positioned near the lifeboat launching system, and one on the lifeboat. Both machines ran MS Windows operating systems and were connected via a wireless network.

The lifeboat computer was an industrial PC equipped as an IEEE 802.11b wireless LAN client and using DaqBoard 2000 hardware to monitor the lifeboat side instruments via a proprietary 16-channel signal conditioner. A signal conditioner description and a list of lifeboat channel assignments complete with gain and filter settings for each instrument are included in Appendix C. The lifeboat PC also monitored the lifeboat DGPS receiver via a serial port connection.

The key software components on the lifeboat PC were: PCAnywhere, host version, to enable remote control from the shore-side computer; DaqView and MS Excel for calibration procedures and data viewing; LifeboatLogger custom software for data acquisition; LifeboatCal custom software for post-calibration of

data; and Tardis time synchronization software, slave. Descriptions of the LifeboatLogger and LifeboatCal custom software are included in Appendix C.

The lifeboat PC was used to acquire and log lifeboat data that was then saved to the system's hard drive in a comma separated value (CSV) text file format.

The shore side computer was a desktop PC equipped as an IEEE 802.11b wireless LAN system access point and using DaqBoard 2000 hardware to monitor the shore side instruments via a proprietary 16-channel signal conditioner. The channel assignments, complete with gain and filter settings for each shore side instrument, are included in Appendix C.

The key software components on the shore side PC were: PCAnywhere client version to enable remote control of the lifeboat computer; DaqView and MS Excel for calibration procedures and data viewing; ShorebaseLogger custom software for data acquisition; ShorebaseCal custom software for post-calibration of data; Tardis time synchronization software, master. Descriptions of the ShorebaseLogger and ShorebaseCal custom software are included in Appendix C.

The shore PC was used to acquire and log lifeboat data that was saved to the system's hard drive in a CSV text file format. The shore side PC was further utilized to start and stop lifeboat data acquisition and to transfer data files from the lifeboat to the shore PC. Custom software was then run on the shore side PC to perform a post-calibration on the raw data to produce calibrated data. The shore side PC included a CD-R drive that was employed to archive both the raw and calibrated lifeboat and shore side data files.

Video records of the tests were recorded with two fixed cameras capturing beam and quarter view video of boat deployments and a third mobile camera used to acquire video of selected views. All video was NTSC standard and recorded in mini-DV format. Still photographs were taken with digital cameras.

The video recorders and the shore side PC were installed in a portable shelter located on the steel platform close to the stowed position of the lifeboat. This location placed the operator of the data acquisition system in a convenient position to monitor lifeboat trials, to control video recording and to use the shore side PC to start and stop the data acquisition as required on the shore and in the lifeboat.

The data acquisition system was developed to be transportable. After trial use and proof-of-concept demonstration with the training facility lifeboat, the data acquisition system should be ready for use on an offshore installation in calm and moderate weather conditions where the data collected would then be directly comparable to the results of scale-model testing.

5.3 Coordinate System

The coordinate system used in the analysis of this series of experiments was a global system using latitude and longitude obtained from the GPS installed in the lifeboat. The origin of an x, y, z grid was chosen at the GPS antenna in the lifeboat while the lifeboat was stowed in the davits. The conversion of latitude and longitude to x, y was performed with the LifeboatCal custom software as follows:

For any given latitude and longitude pair,

$$\text{LatAdj} = \text{Lat} - \text{Latitude of origin} \tag{2}$$
$$\text{LongAdj} = \text{Long} - \text{Longitude of origin} \tag{3}$$

$$Y = (\text{LatAdj} \cdot \text{MPD}) \cdot 1000$$
$$X = (\text{LongAdj} \cdot \text{MPD} \cdot \text{Cos(Lat in radians)}) \cdot (-1000)$$

where MPD is 111.317

Lifeboat vertical position z was not obtained from the GPS unit but was obtained from measurements of lifeboat winch payout and was monitored only during lifeboat lowering.

6.0 TEST PLAN

The test plan experiments were organized into several series as shown in Table 6.1. Series B involved TEMPSC deployment in calm conditions to collect data for the 12 evacuation performance measures identified in Section 3.0. The other test series were designed to collect data for the supplementary performance measures described in Section 4.0 with Series A investigating aborted launch shock loads in the lifeboat fall wires; Series C investigating acceleration and turning aspects of lifeboat manoeuvring; Series D investigating lifeboat bollard pull; Series E investigating lifeboat GM; and Series F investigating the lifeboat's heave, pitch and roll behaviour. For all series, trials were run with the lifeboat in both the light condition and loaded to approximately 80 to 90 percent of the full rated capacity. The test plan trial filenames are listed in Appendix F.

Table 6.1 Test Matrix		# of Trials heavy	light
Series A	Aborted Launch Shock Loads with stopping distance: Just after start of lowering (~1.5 m) Mid-way point of lowering (~4.5 m) Just above water entry point (~7 m)	 1 1 1	 1 1 1
Series B	Lifeboat Deployments using configuration: Flex Boom & Power Flex Boom & ***No*** Power ***No*** Flex Boom & Power	 1 1 1	 1 1 1
Series C	Accelerations (to 6 kn & max speed) and Turning Circles	4 2	2 2
Series D	Bollard Pull	2	2
Series E	Inclining & Determination of GM	1	1
Series F	Heave, Pitch and Roll Decay	1	1

6.1 Test Methodology

The calibrations followed the Institute for Ocean Technology's standard procedure for calibration while the general tests followed the methodology presented below.

As the winch supplied with the launching system lacked sufficient power to recover the lifeboat in the loaded condition, water tanks were used to ballast the boat so that the boat could easily be de-ballasted before recovery. The issue of the winch providing sufficient power to recover the lifeboat only in light condition or with "crew only" is typical of modern launching systems. This limitation is rationalized by recognizing that the launching system is intended only to deploy the fully loaded lifeboat and subsequent rescue is not likely to involve the recovery of the fully loaded lifeboat by the launching davits. In any case, this recovery power deficiency proved to be a significant logistical issue in the lifeboat testing as each ballast/launch/de-ballast cycle required about 2 hours to complete with the de-ballasting consuming about half of this time. This ballast/deballast time proved to be the limiting factor that determined the number of test runs that could be completed per day. A description of the ballast system components is included in Appendix D.

<u>Series A</u>: Shock loads on fall wires

Series A is concerned with assessing the fall wire loads that develop when TEMPSC lowering is stopped before the boat is waterborne.

With lowering typically started and stopped from within the enclosed lifeboat, crewmembers managing the launch have to be specifically trained to perform lowering tasks. At the start of such launch training, inadvertent lowering stoppages occur frequently though training conditions are controlled and ideal.

Typically, the number of unintentional stoppages decreases as the trainees develop the required psychomotor skills and kinesthetic awareness but the degree of lowering control is not assured. Furthermore, deliberate stoppages may be necessary to time splash-down with favourable wave conditions or to avoid collision with debris. It is therefore clear that lowering stoppages should be anticipated and that lifeboat launching systems must be designed and built to withstand such occurrences under the conditions that may prevail during emergency evacuation.

Supporting this, the International Life-Saving Appliance (LSA) Code, which is mandatory under SOLAS, requires that winch brakes must be "capable of stopping the descent of the survival craft...and holding it securely when loaded with its full complement of persons and equipment" (6.1.2.11). However, the LSA Code does not specify stopping distances or place any requirements or limits on braking force. Manufacturers employ various brake systems and stopping behaviour is observed to vary significantly.

As an organization delivering training to lifeboat users, the Marine Institute reduces risk to participants during lifeboat launch training by loading the lifeboat with lowering crew only so that the lifeboat is typically loaded to less than 10 percent of its rated capacity. Any "shock" loading of the boat fall wires experienced during lowering stoppages would then be less than with a fully laden lifeboat and should be well within the limits imposed by the minimum factor of safety of six required by the LSA Code (6.1.1.6). However, since the intent of series A was to investigate the shock loading with the lifeboat fully loaded (or nearly so), risk to participants was assessed to be higher than tolerated during normal training evolutions.

Series A trials were therefore undertaken without participants in the lifeboat. The PrOD tagline was disconnected and the boat was ballasted using the water tank system. Lowering was then controlled by a team member on deck at the starboard side of the boat and positioned so as to manage the lowering control wire that operated the winch brake release. This lowering control wire was pulled to initiate lowering after the data acquisition operator had started the data acquisition system. With the fall wires paying out and the lifeboat lowering, the control wire was then released to reapply the winch brake and "abort" the launch. This stop to lowering resulted in an increased load on the fall wires as the lifeboat's descent was halted. This load was then calculated using the values obtained for the accelerations acting on the boat.

Using this method, the shock loads were assessed when aborting the launch at three different heights. The first was shortly after the start of TEMPSC lowering with the fall wire payout at about 1.5 m, the second was with the lifeboat lowered about halfway or a payout of about 4.5 m and the third was with the boat lowered to just above the water corresponding to a payout of about 7 m. For expediency, TEMPSC lowering was not started from the stowed position each time. Instead,

the stops were done in succession from the highest to the lowest. This approach was taken only after validating that (for a given ballast condition) the lowering speed was not dependent on the payout, but was constant after a quick ramp-up to the pre-set lowering speed that was hydraulically controlled by the winch.

Following the final (7 m) stop, the TEMPSC was lowered until fully waterborne so as to monitor the system and collect data during water entry. However, the boat was not released from the falls or manoeuvred through a sail-away phase. The lifeboat was then de-ballasted, hoisted to the stowed position and made ready for the next trial.

After completing tests with the lifeboat in the heavy condition, additional tests were conducted to obtain aborted launch shock load data with the boat in the light condition.

<u>Series B</u>: TEMPSC deployments with selected system configurations

The intent of this series was to demonstrate the use of a data acquisition system designed to collect standard performance measure data from full-scale lifeboat deployments on offshore installations for comparison with data from model-scale evacuation system performance tests.

To this end, the TEMPSC was manned with crew only, ballasted with the water tank system and deployed from the Marine Institute facility using a launch sequence appropriate to an offshore installation. After a signal from the data acquisition operator, lowering was initiated by the lifeboat crew who then controlled the deployment through to fall release and sail-away on an escape heading established by the PrOD tag line and approximately orthogonal to the platform side.

Additional trials were then undertaken with the lifeboat and launching system configured so as to isolate and better investigate the contributions of lifeboat power and PrOD assist to lifeboat sail-away. The first variation involved launching the lifeboat without the PrOD tagline connected so that lifeboat power alone was used during sail-away. The second variation involved launching the lifeboat with the lifeboat engine running but the transmission in neutral so that PrOD assist only was used during sail-away. All three configurations were repeated with the lifeboat in the light condition.

<u>Series C</u>: Lifeboat accelerations and turning circles

The intent of Series C was to demonstrate the extended use of a data acquisition system to collect supplementary performance measure data from a full-scale lifeboat and investigate lifeboat acceleration and turning characteristics that could not easily be assessed during a typical deployment.

Series C trials were conducted with the lifeboat afloat, manned with crew only and ballasted with the water tank system. At the beginning of each trial the lifeboat was stopped with the engine idling, the transmission in neutral and the wheel "midships". After observing the boat to be stable on an appropriate heading and confirming the data acquisition system was started, the transmission was engaged, the throttle immediately moved to full and the boat accelerated in a straight line while maintaining the initial heading until maximum/constant speed was reached. After then traveling several boat lengths at maximum speed, the wheel was turned "hard over" and held in the "lock" position so that the boat turned in a complete circle. The helm was kept over until boat had described a second circle when the wheel was then used to check the turn and place the boat on the original heading still running at full throttle. After traveling several boat lengths at maximum speed, the wheel was then turned hard over in the other direction and held in the lock position so that the boat turned two complete circles in the opposite direction. The wheel was then used to check the second turn and again place the boat on the original heading still running at full throttle. The boat was then run for several boat lengths at maximum speed to end the trial.

Series C trials were also completed with the boat in the light condition.

<u>Series D</u>: Lifeboat bollard pull

The lifeboat bollard pull was determined by means of a simple setup that used webbing slings with an in-line load cell to secure the lifeboat's stern lifting hook to a strong point on the platform. With this "stern line" slack, the lifeboat was then controlled with light tag lines so that the boat was lined up with its bow away from the platform, the engine idling, the transmission in neutral and the wheel "midships". After starting the data acquisition system, the transmission was engaged, the throttle slowly moved to full so that the stern line was placed under load. The tag lines were simultaneously eased and the boat was run at full power for several minutes against the restraining action of the stern line.

Series D trials were also completed with the boat in the light condition.

<u>Series E</u>: Inclining experiments

Inclining experiments were performed to determine the transverse metacentric height (GM) of the lifeboat for the loaded and light conditions. Weights were used to induce a heel angle. An experiment was started with these weights on the lifeboat centreline. With the data acquisition system running, the weights were shifted a known distance to starboard and the heel angle of the boat recorded. The weights were shifted back to the centerline and the heel angle recorded again. The weights were then shifted to port a known distance and the heel angle recorded. Finally, the weights were returned to the centreline and the heel angle recorded to end the experiment.

Series F: Heave, pitch and roll decay experiments

Heave, pitch and roll decay experiments were performed to determine the natural heave, pitch and roll periods of the lifeboat for the loaded and light conditions.

The heave decay experiment was performed by conducting an on-load release of the lifeboat. With the PrOD tagline disconnected and the engine stopped, the lifeboat was lowered with crew only until waterborne but was not released from the falls. The winch was then operated to tighten the fall wires, hoisting the boat again but only until the propeller shaft was even with the water surface. At that point, the keel and part of the boat bottom were still submerged. With the data acquisition system running, the release gear hydrostatic interlock was overridden and the release gear operated to disengage the boat from the falls. The boat then settled by about 0.5 m and rose again creating a heave oscillation that was monitored as it decayed.

The pitch decay experiment was performed in similar fashion to the heave experiment described above except that, after lowering the boat to the water, the aft fall wire was disengaged so that only the forward fall wire was used to hoist the boat in preparation for the on-load release. The boat was thereby positioned with its bow pitched up at a 10° angle and the release created a pitch oscillation that was monitored as it decayed.

The roll decay experiment was performed with the boat afloat and disengaged from by the falls. The boat crew simply moved from side to side to induce rolling. The boat crewmembers then positioned themselves on the centreline and the roll oscillation was monitored as it decayed.

7.0 DATA ANALYSIS AND DISCUSSION

The results from each test were recorded in CSV text file format and the custom software was run for post-calibration to generate calibrated values that were checked at the time of testing. The calibrated CSV files for each test constituted a multiplexed time history from all data channels. Some basic analysis was performed on-site with MS Excel but the results were treated as preliminary.

For detailed analysis, the CSV files were imported into a program called Wavemetrics Igor Pro. This software tool is designed for visualizing, analyzing and presenting time series data. The imported CSVs for each test series was then stored as an Igor "experiment". The program was used to extract information for the particular performance measure investigated in each series. To this end, the test data were processed using a variety of Igor tools and procedures to convert the initial results into plots and graphs for further interpretation. Values were obtained from these plots and graphs to populate cells in Microsoft Excel spreadsheets where further manipulations were performed to support the analysis.

7.1 Series A: Shock Loads on Fall Wires

Figure 7.1 shows the vertical accelerations measured in the stern of the lifeboat for a representative aborted launch fall wire shock load trial with the TEMPSC loaded to 78 percent of full rated capacity. This graph shows the acceleration change as lowering is commenced and then stopped at a fall wire payout of 4.5 m. The stop occurs in less than 0.2 seconds after the winch brake is reapplied, causing the acceleration to peak. The lifeboat then "bounces" to produce a decaying sinusoidal oscillation in the acceleration.

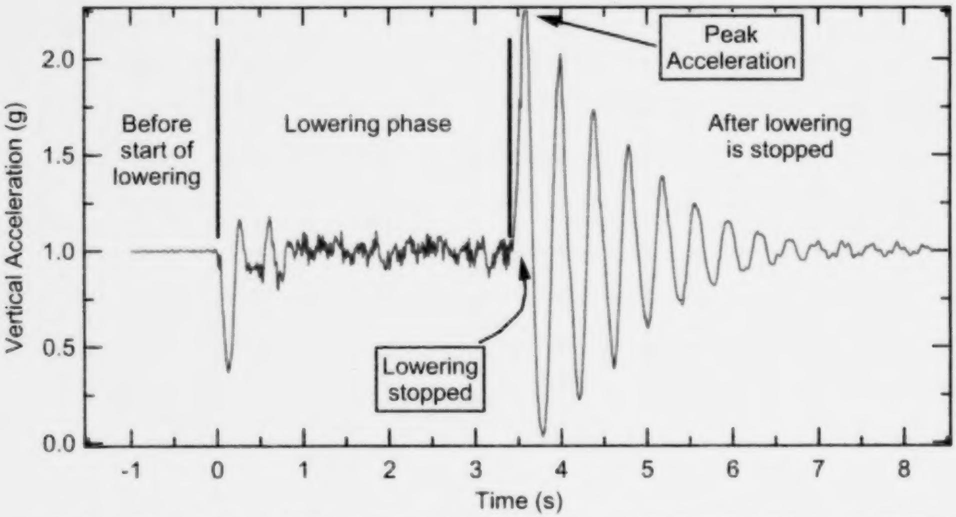


Figure 7.1 Shock Load Vertical Accelerations at TEMPSC Stern Fall Wire Location

A summary of TEMPSC vertical accelerations for the Series "A" trials is presented in Table 7.1. Values are shown for the boat in both the light condition and loaded to a nominal 78 percent of full capacity and for launches aborted after lowering selected distances from the stowed position. For comparison, the maximum accelerations are provided at three locations in the boat.

Table 7.1 Aborted Launch Vertical Accelerations

Trial Conditions			Payout			Maximum Acceleration		
Run Name	Boat Loading	Stop Dist	Delta [mm]	Time [s]	Rate [m/s]	Bow [g]	Midships [g]	Stern [g]
1P1P5_002	Heavy	1.5 m	1605	2.09	0.768	2.035	2.157	2.250
2P4P5_002	Heavy	4.5 m	2727	3.46	0.788	2.007	2.212	2.313
3P7P0_002	Heavy	7.0 m	2003	2.59	0.773	2.002	2.198	2.310
L_1P1P5_001	Light	1.5 m	1376	2.60	0.529	2.095	2.212	2.319
L_2P4P5_001	Light	4.5 m	2643	4.80	0.551	2.157	2.193	2.169
L_3P7P0_001	Light	7.0 m	2645	4.66	0.568	2.101	2.136	2.125

Some insight into the actual fall wire shock loads can be gained by using the accelerations and the mass of the boat and calculating the force exerted on the line. If we take the highest acceleration of ≈ 2.3 g experienced at the stern of the boat and assume that the stern fall wire supports half the mass of the boat, 69.5 kN is the corresponding value calculated for the maximum fall wire load. This value must then be compared to the rated safe working load for the fall wire.

The safe working load for a wire rope is generally established for static conditions and obtained by using standardized test equipment and methods to slowly apply increasing load to a new sample of the rope until it fails. The SWL is then taken to be some acceptable fraction of this ultimate strength. The ultimate strength of the wire rope supplied for the falls in the full-scale test system was certified to be 28.8 tonnes. Applying the SOLAS standard factor of safety of 6:1 establishes a nominal safe working load of 4.80 tonnes. This equates to a line load limit of 47.0 kN.

Therefore, in the example above, the 69.5 kN calculated value for maximum shock load exceeds, by a factor of 1.5, the nominal safe working load for the fall wire.

The fall wire shock load issues are further compounded by the passenger load in the boat and the lowering speed during launch. Note that the payout rate increases as the lifeboat loading is increased and was observed to range from a low of 0.53 m/s for the light boat to a high of 0.79 m/s with the boat loaded at a nominal 78 percent of full capacity. The TEMPSC lowering speed would likely be further increased with the boat loaded to full capacity. Both the full passenger load and the increase in lowering speed would then tend to increase the fall wire shock loading experienced when aborting a launch.

All measured the lowering speeds did conform to the requirements of LSA Code (6.1.2.8), which states that the lowering speed "shall not be less that that obtained from the formula":

$$S = 0.4 + 0.02H \tag{4}$$

where:

S is the lowering speed in metres per second and

H is the height in metres from the davit head to the waterline

7.2 Series B: TEMPSC Deployments

The TEMPSC was deployed in the loaded condition following standard procedure so that the PrOD tag line was connected and both the tag line and the lifeboat engine assisted the lifeboat in clearing the "installation". The loaded TEMPSC was also launched using two non-standard procedures: one deployment with PrOD assist only (no engine power used to help clear the installation) and the other deployment with engine use only to clear the installation (PrOD tag line disconnected before lowering). These three deployment configurations were then repeated but with the lifeboat in the light condition and loaded only with lowering crew.

Data was collected for the various deployment configurations that, in a seaway, would allow the assessment of the 12 performance measures listed in Table 3.1. However, in the calm conditions experienced at the Marine Institute training facility location, there was little weather challenge or variation to provide significant results. Accordingly, there were no collisions during or after launch, the launch position was consistent relative to the target point, there was no setback or progressive setback, the path lengths traveled by the lifeboat from the launch position to the splash-down border and the rescue border were optimal, and the accelerations during lowering and sail-away were not influenced by weather.

It is significant that the data acquisition system itself was sufficiently exercised to demonstrate "proof-of-concept" for this approach to data collection. In general, all instrumentation functioned well and very few problems were encountered with the capture of critical shore side or lifeboat data. Some minor incremental improvements may have been obtained with additional instrumentation to directly monitor both the loads in the boat falls and the pressure in the PrOD hydraulic cylinder. Additionally, a more powerful lifeboat PC may have supported higher sampling rates for data channels in the lifeboat.

The only noteworthy issue with data acquisition during TEMPSC deployments related to accuracy of the boat position determined with GPS technology. A high quality marine differential GPS unit was selected for use because of its advertised position accuracy of less than 1 m horizontal. However, to achieve

this accuracy, at least five satellites had to be visible to the GPS receiver and a value of less than 4 obtained for the "position dilution of precision" (PDOP). This PDOP value is a measure of the geometrical "strength of figure" of visible satellites or the suitability of the satellite constellation geometry for triangulating the position of the GPS receiver. Unfortunately, the natural elevation cut-off angles in the launch location at the base of the Southside Hills resulted in reduced satellite visibility and occasional unfavourable satellite geometry. The Southside Hills may also have degraded GPS accuracy by introducing multipath or signal reflection errors. Consequently, the 2-D plot of the TEMPSC track or path sometimes displayed "jumps" of up to several metres in the lifeboat position. After jumping, the position could quickly jump back or be maintained in the new position for a few seconds or indefinitely. This noise was thought to not be random but to be caused by the changing position of the orbiting satellites affecting PDOP or by the GPS unit dropping and/or acquiring a satellite.

A plot of TEMPSC track during splash-down and sail-away that does not display the position "jumps" described above is shown in Figure 7.2. This "clean" track would support the identification of splash-down and rescue zone boundary crossing times and the calculation of corresponding path lengths to those crossing points. The required performance measure information is then easily obtained.

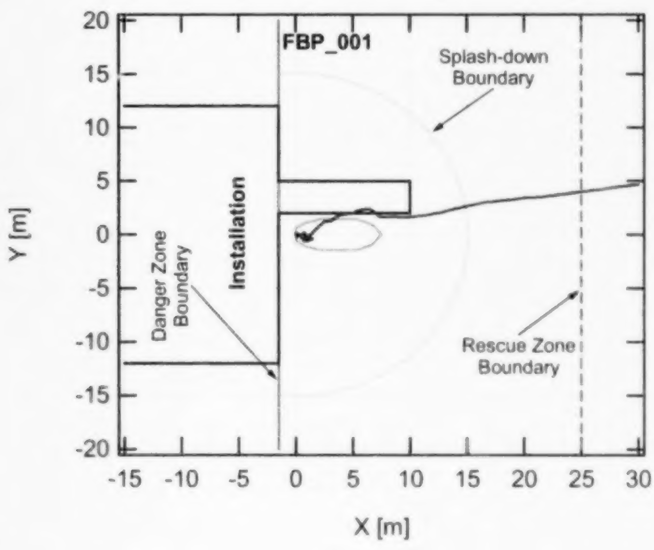


Figure 7.2 Clean Plot of the TEMPSC Track during Splash-down and Sail-away

For comparison, a "noisy" plot of the TEMPSC track during splash-down and sail-away is shown in Figure 7.3. In this trial, the "jumps" in position make it difficult to accurately determine the splash-down zone boundary crossing time but,

because of a "jump back" does not appear to affect the rescue zone boundary crossing time. Even more significantly, the calculation of the respective path lengths to the two boundary crossing points is complicated because the jumps in position drastically increase the apparent path lengths when compared to the straight-line course (and short path lengths) that testing personnel observed in this deployment. Fortunately, the quality of position data on most of the deployment trials was better than obtained on this example but position error was frequently more than the advertised 1 m horizontal.

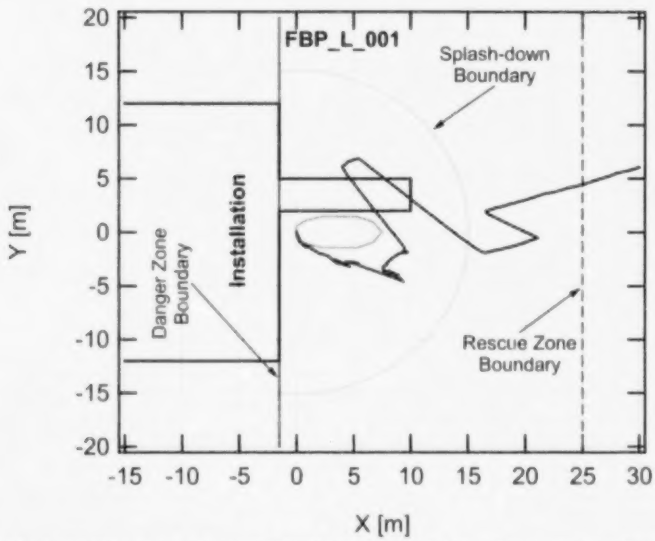


Figure 7.3 Noisy Plot of the TEMPSC Track during Splash-down and Sail-away

Such position can likely be corrected with scheduling or management of trial times and further trials should be preceded with an assessment of GPS satellite visibility and corresponding PDOP values. This will require on-site checks to verify the accuracy of the GPS position information and to investigate if position accuracy can be improved by limiting testing to periods when sufficient satellites are visible and/or PDOP values are acceptable. The impact of a change in location for trials should similarly be assessed and this would be particularly important before attempting trials from an actual offshore installation.

If selecting the time and location of trials does not provide sufficient position accuracy with standard marine DGPS equipment, other approaches can be utilized. Post-processing is one option that may be able to adjust data to correct for errors. One simple post-processing approach is to use a second and identical GPS antenna and receiver in a fixed and known position near the trial area. With both systems performing similarly, the position drift and noise observed at the fixed system can be used later to adjust position information obtained with the mobile GPS system. Additional post-processing options are available or, alternatively, more sophisticated GPS instruments can be employed.

7.3 Series C: TEMPSC Accelerations and Turning Circles

Two acceleration trials were completed with the TEMPSC manoeuvred in a straight-line and accelerated from stop to maximum speed. Subsequently, four more trials were completed that combined the straight-line boat operation with additional manoeuvring to collect turning circle data. These four trials were completed in pairs with the boat operated in opposite directions on alternate trials so as to minimize any effect of wind and current on the trials. Figure 7.4 shows the TEMPSC track for a representative trial where acceleration and turning information was collected.

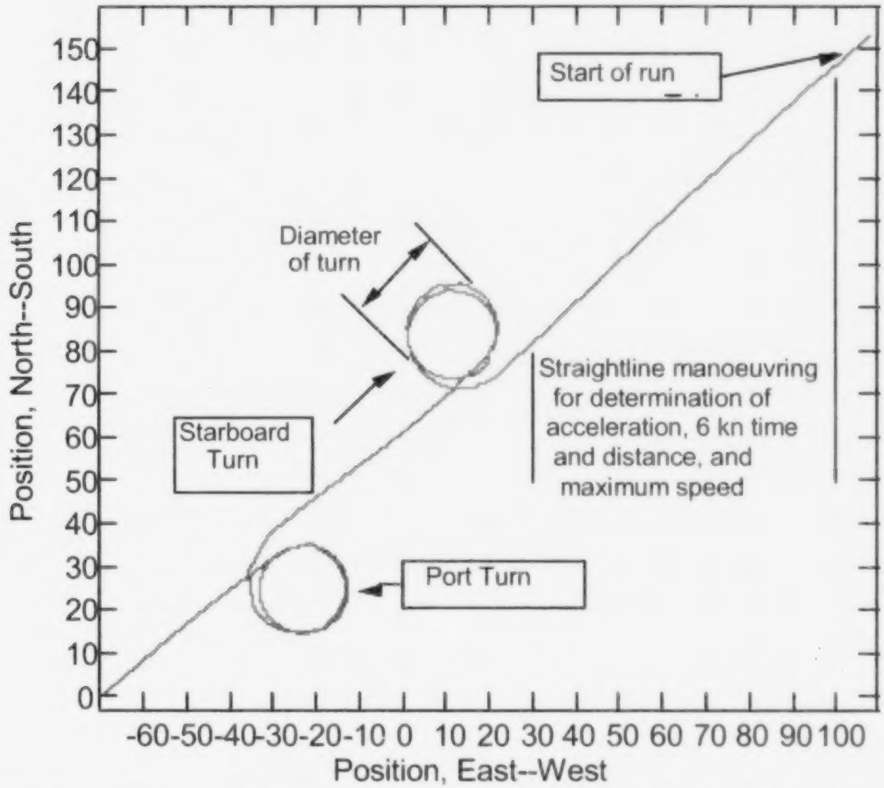


Figure 7.4 Track of TEMPSC for a Typical Acceleration and Turning Circle Trial

The acceleration and speed data collected in all six trials is presented in Table 7.2. Note that, compared to the loaded condition, the light lifeboat accelerates more quickly and only requires half the time and distance to reach a speed of 6 kn. Maximum speed is slightly increased for the light boat.

Table 7.2 TEMPSC Acceleration and Speed

Trial Conditions		Max Accel	Distance	Time	Max Speed
Run Name	Loading [%]	at Start [g]	to 6 kn [m]	to 6 kn [s]	Observed [kn]
AC_001	91	0.04067	29.4	14.4	6.25
AC_002	90	0.04748	19.9	11.8	6.52
AC_003	91	0.04404	27.3	13.6	6.52
AC_004	91	0.04505	25.6	13.9	6.47
L_AC_001	Light	0.07158	12.1	7.0	6.78
L_AC_002	Light	0.07122	13.9	7.6	6.57

For the TEMPSC turning behaviour investigation, the Z-rate (angular velocity) data from the motion pack in the TEMPSC was used to obtain an average turning rate. This rate compared well with the turning rate calculated using TEMPSC position and elapsed time. Position information was also used to simply determine the diameter of turning circles described by the TEMPSC at full speed. The turning information is presented in Table 7.3. Note that the time required for the boat to complete a turn was the same for the boat in both the light and the loaded condition. However, in the light condition, the diameter of the turn described by the boat was significantly larger than that experienced in the heavy condition.

Table 7.3 TEMPSC Turning Circle Performance

Trial Conditions		Starboard Turning Circles			Port Turning Circles		
Run Name	Loading [%]	Dia. of Turn [m]	Time for Turn [s]	Avg. Rate for Turn [deg/s]	Dia. of Turn [m]	Time for Turn [s]	Avg. Rate for Turn [deg/s]
AC_003	91	20.1	29.1	12.6	21.1	29.6	12.1
AC_004	91	20.0	29.9	12.4	20.0	29.7	12.1
L_AC_001	Light	25.2	29.4	12.4	25.4	29.9	12.1
L_AC_002	Light	26.1	29.6	12.3	25.2	30.1	11.9

7.4 Series D: TEMPSC Bollard Pull

The bollard pull of the TEMPSC was investigated with two trials completed in each of the loaded and the light conditions. The boat was run up to maximum throttle and load data was collected for durations varying from approximately 30 seconds to 1 minute. The mean bollard load was then calculated using an Igor function and is reported in Table 7.4. The average mean bollard load was 3.14 kN.

Table 7.4 TEMPSC Bollard Pull

Trial Conditions		Mean
Run Name	Loading [%]	Bollard Load [kN]
H_001	87	3.14
H_002	87	3.11
L_001	Light	3.18
L_002	Light	3.14

7.5 Series E: TEMPSC Inclining Experiments

The inclining experiments were conducted with the TEMPSC in both the heavy and the light conditions. The heavy trial was conducted with a total lifeboat weight of 6711 kg, which represented 91 percent of the full rated capacity. This weight included the inclining weight of 200 kg. Table 7.5 presents the inclining experiment results for the loaded lifeboat.

Table 7.5 TEMPSC Inclining Experiment Results for Loaded Condition

Inclining		Weight Shift				
Weight [kg]	Angle, ϕ [deg]	Port [m]	Centre [m]	Stbd [m]	Moments [kg-m]	Tan ϕ
200	0.79	-	0.0	-	0.0	0.0139
200	-4.72	-	-	-1.5	-300.0	-0.0826
200	0.72	-	0.0	-	0.0	0.0126
200	6.32	1.5	-	-	300.0	0.1108

Using this data, the transverse metacentric height can be calculated using:

$$\overline{GM} = \frac{w \times d}{\Delta \times \tan\phi} \qquad (5)$$

where:

$\overline{GM}$ = Transverse metacentric height, m
w = Inclining weight, kg
d = Weight shift, m
Δ = Weight of the TEMPSC, kg
ϕ = Angle of inclination, degrees

Furthermore, with inclinations made to port and starboard, the plot of the inclining moment (w x d) vs. tanϕ should be a straight line if the lifeboat's displacement (weight), Δ, is constant. Any variation from a straight line indicates that the conditions for conducting the experiment were not satisfactory, or errors have been made. The slope of the straight line fitted to the data is:

$$slope = \frac{w \times d}{\tan\phi} \tag{6}$$

The slope can be used to solve for $\overline{GM}$ as follows:

$$\overline{GM} = \frac{w \times d}{\Delta \times \tan\phi} = \frac{slope}{\Delta} \tag{7}$$

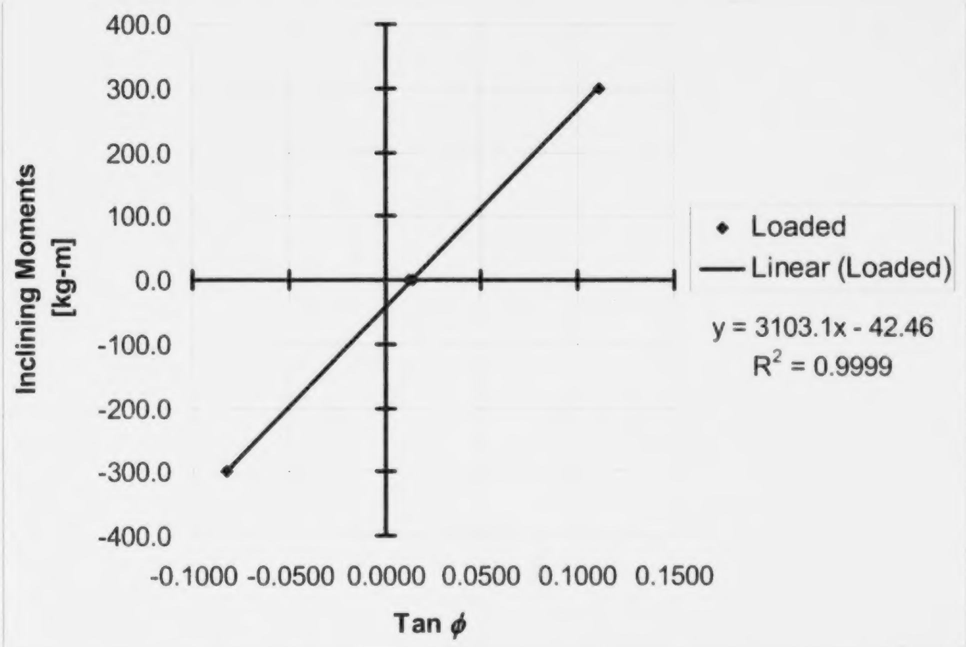


Figure 7.5 Inclining Moments and Angles of Inclination for the TEMPSC at 91 percent of Full Rated Capacity

Therefore, using the slope value of 3103 kg-m from Figure 7.5 and dividing by the boat weight of 6711 kg, the TEMPSC's transverse metacentric height is calculated to be 0.46 m with the lifeboat loaded to 91 percent of full rated capacity.

The light inclining experiment was conducted with a TEMPSC weight of 3806 kg including the 200 kg inclining weight. Table 7.6 presents the inclining experiment results for the light lifeboat.

Table 7.6 TEMPSC Inclining Experiment Results for Light Condition

Inclining		Weight Shift				
Weight [kg]	Angle, ϕ [deg]	Port [m]	Centre [m]	Stbd [m]	Moments [kg-m]	Tan ϕ
200	0.46	-	0.0	-	0.0	0.0080
200	-6.55	-	-	-1.5	-300.0	-0.1148
200	0.31	-	0.0	-	0.0	0.0053
200	5.91	1.5	-	-	300.0	0.1035

Plotting the inclining moments vs. tan ϕ, for the light condition, we get:

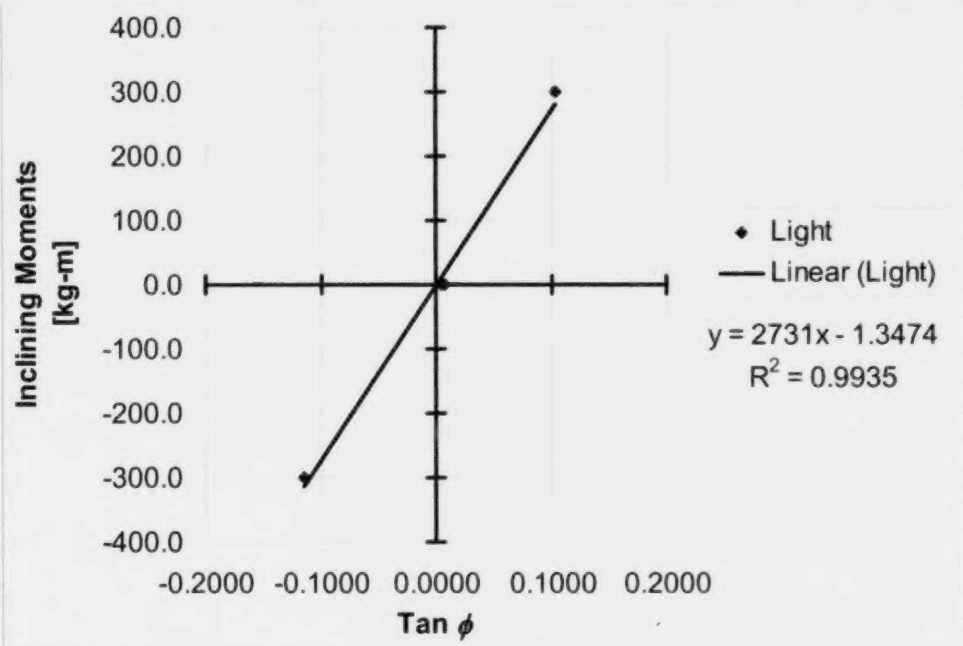


Figure 7.6 Inclining Moments and Angles of Inclination for the TEMPSC in Light Condition

Using the slope value of 2731 kg-m from Figure 7.6 and dividing by the boat weight of 3806 kg, the TEMPSC's transverse metacentric height is calculated to be 0.72 m for the lifeboat in the light condition.

7.6 Series F: TEMPSC Heave, Pitch and Roll Decay Experiments

Heave, pitch and roll decay tests were conducted on the free-floating TEMPSC with a single trial completed in each of the heavy and the light conditions. The test data was analyzed using the GEDAP "decay_analysis" and "damped_sine_fit" programs and is summarized in Table 7.7. Additional data is provided in Appendix E.

Table 7.7 TEMPSC Heave, Pitch and Roll Periods

Run Number	**Period** [s]
H_H_001	2.14
H_P_001	2.18
H_R_001	2.73
L_H_001	n/a
L_P_001	2.28
L_R_001	2.70

REFERENCES

1. Simões Ré, A. and Veitch, B. 2001. Experimental evaluation of lifeboat evacuation performance. *Transactions,* Society of Naval Architects and Marine Engineers, Vol.109, 18 p.

2. Pelley, D., Simões Ré, A., Veitch, B. 2002. Evacuation by lifeboat in extreme seas. *Proceedings, Safety at Sea Conference*, 17 p.

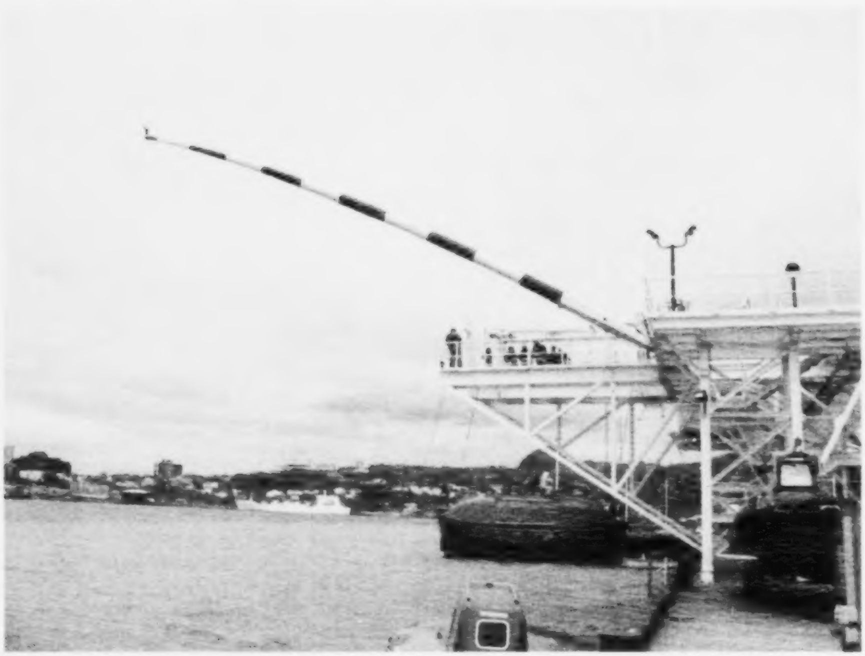
3. Simões Ré, A., Veitch, B., and Pelley, D. 2002. Systematic investigation of lifeboat evacuation performance. *Transactions*, Society of Naval Architects and Marine Engineers, Vol. 110, 20 p.

4. IMO 1997. International life-saving appliance code (LSA Code). International Maritime Organization.

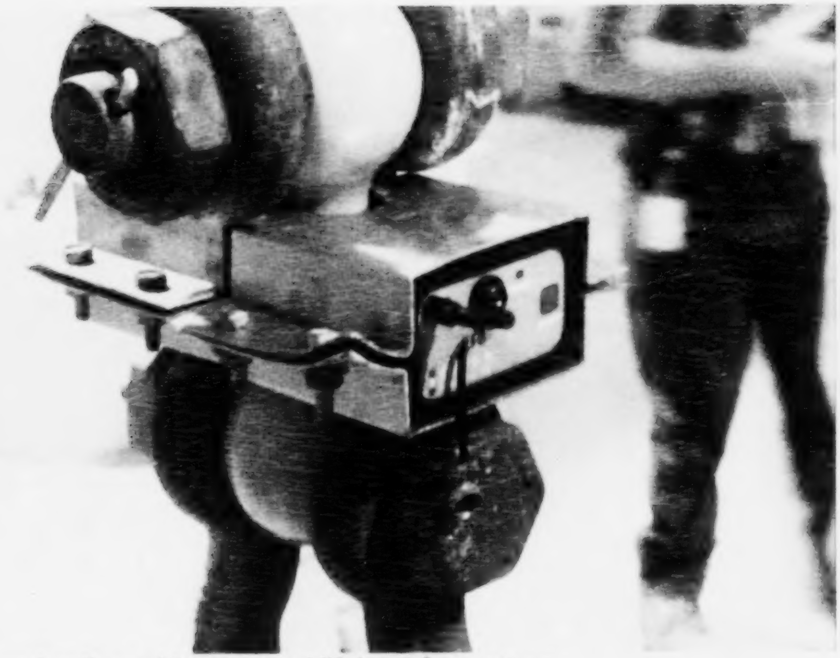
Appendix A

Selected Lifeboat and Launching System Pictures

Training facility location of full-scale trials

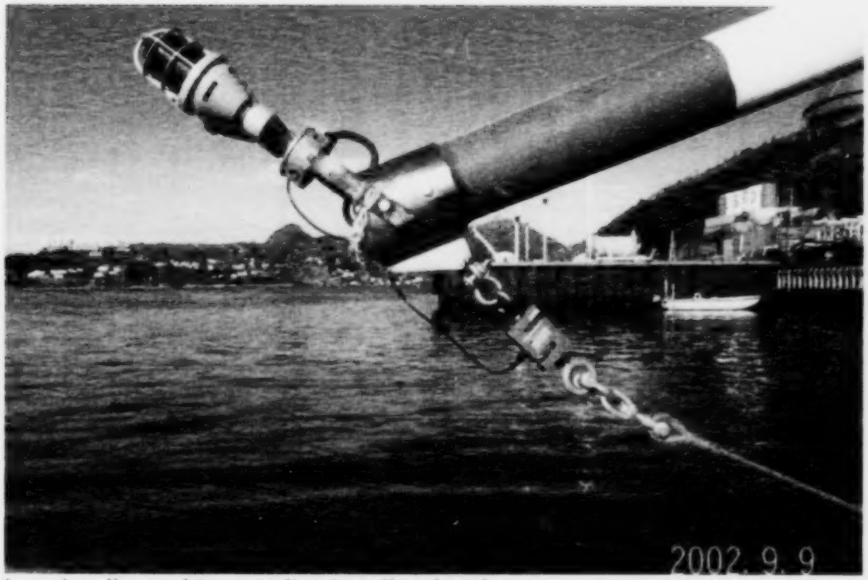


Training facility platform with TEMPSC in mid-launch showing PrOD boom and tagline

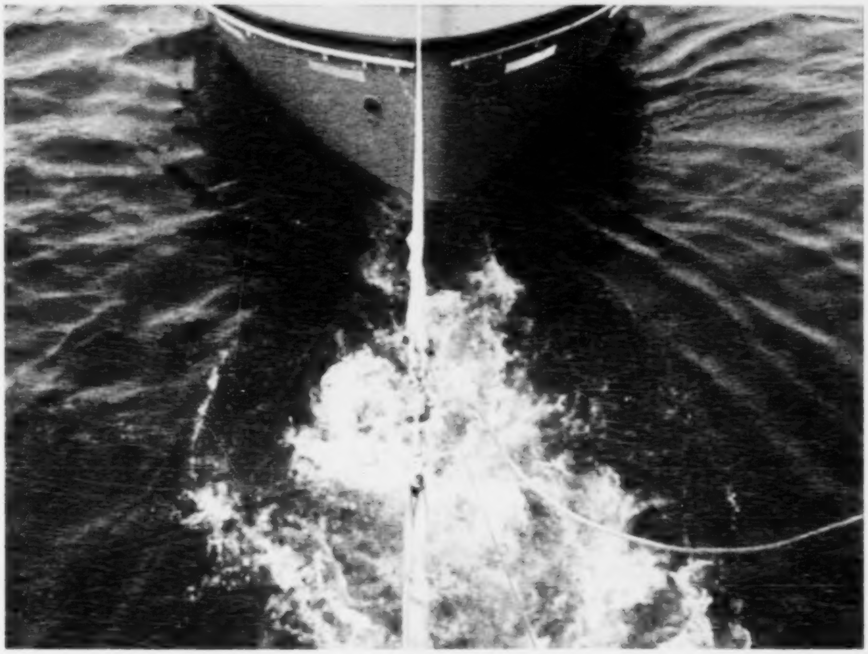


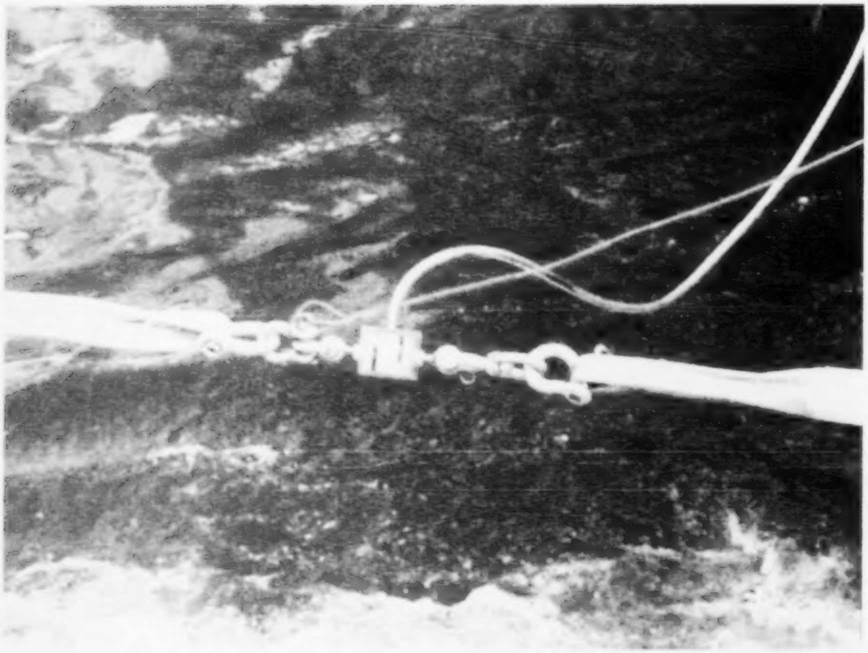
Load cell used to suspend lifeboat from crane

Determining mass of lifeboat

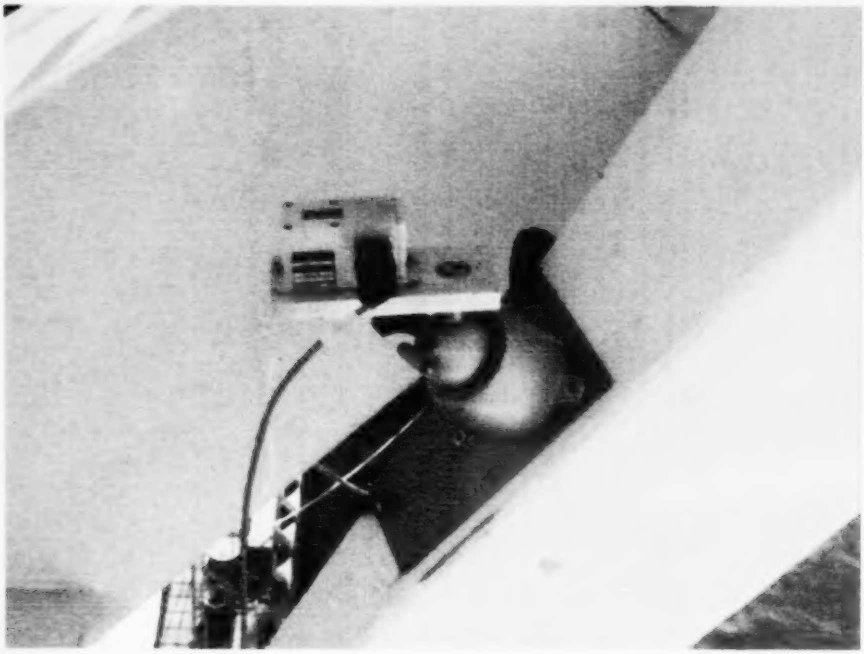


Load cell used to monitor tag-line loads

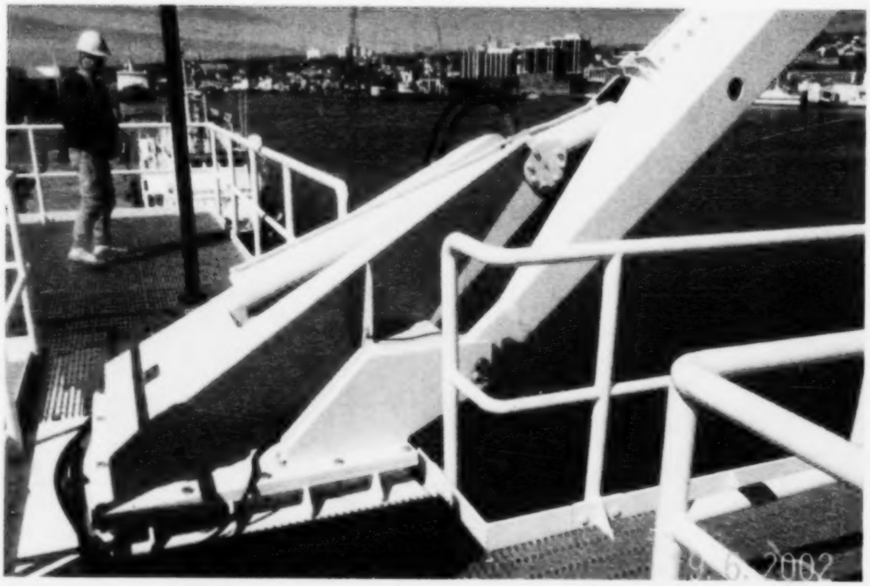

Load cell and tow-line arrangement for bollard pull tests



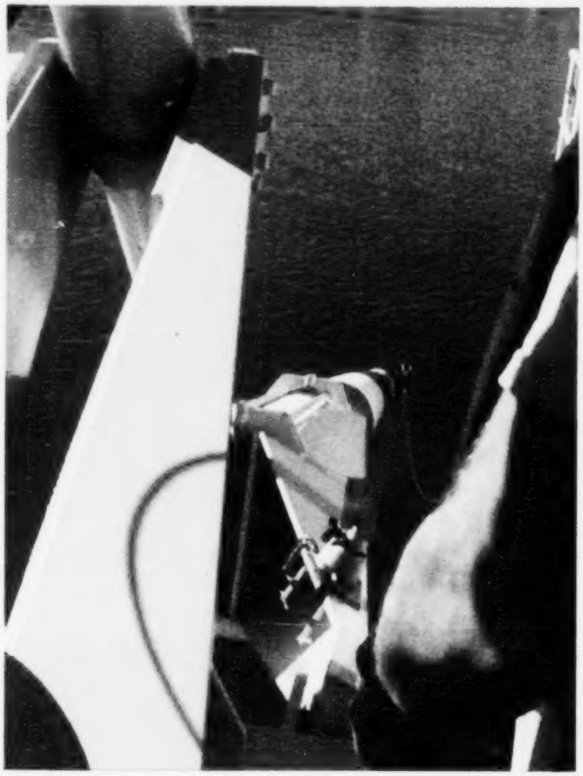
Load cell for bollard pull tests



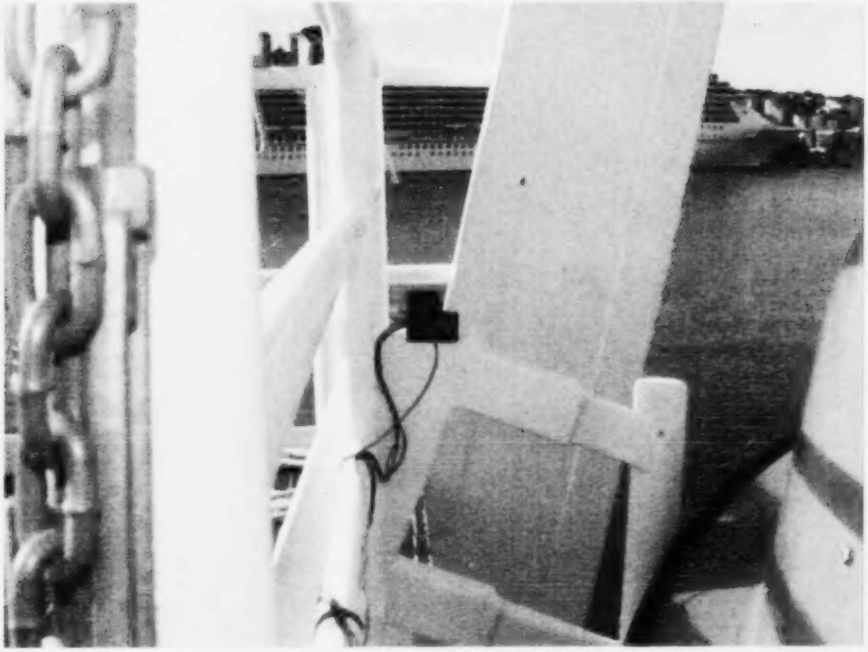
Inclinometer mounted on PrOD boom base to monitor PrOD boom angle



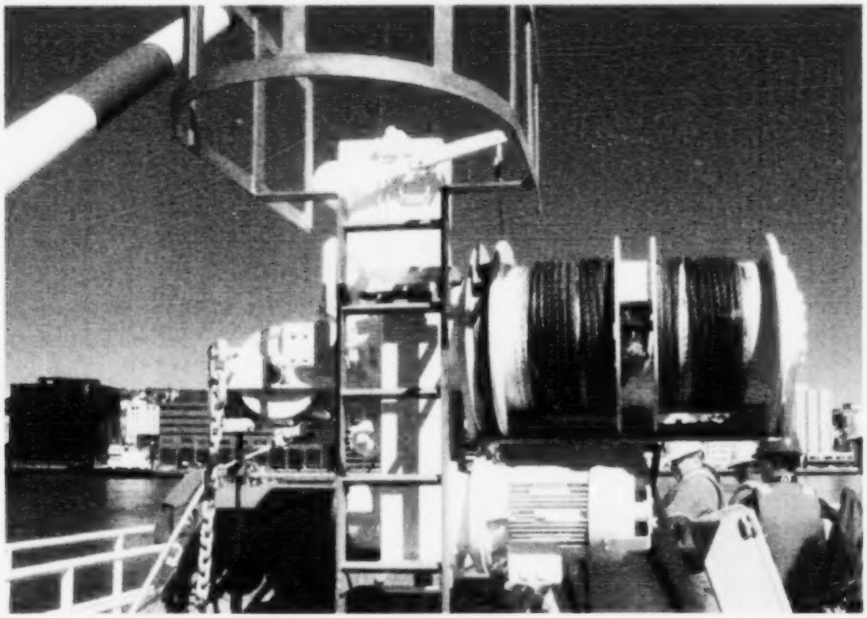
PrOD boom base with boom at "park" position (inclinometer not shown)



PrOD boom base and inclinometer with boom lowered

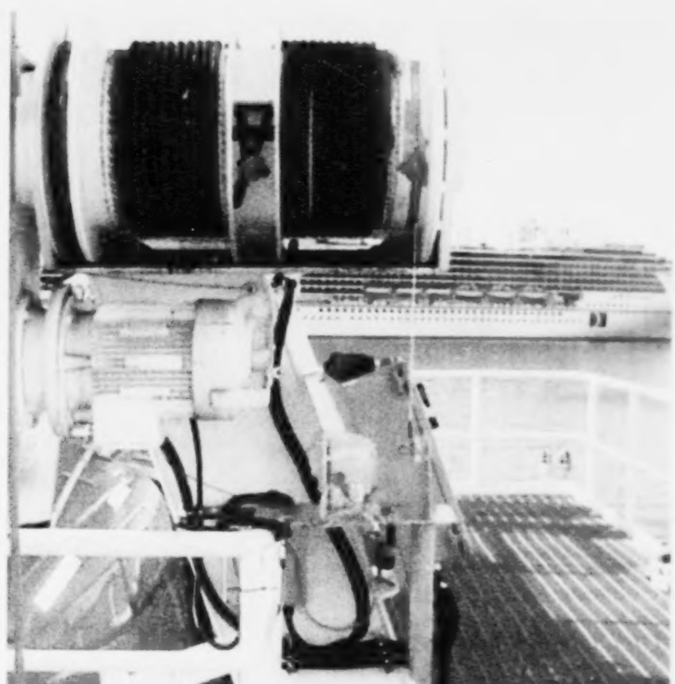


Three-axis accelerometer to monitor platform accelerations during lifeboat deployment

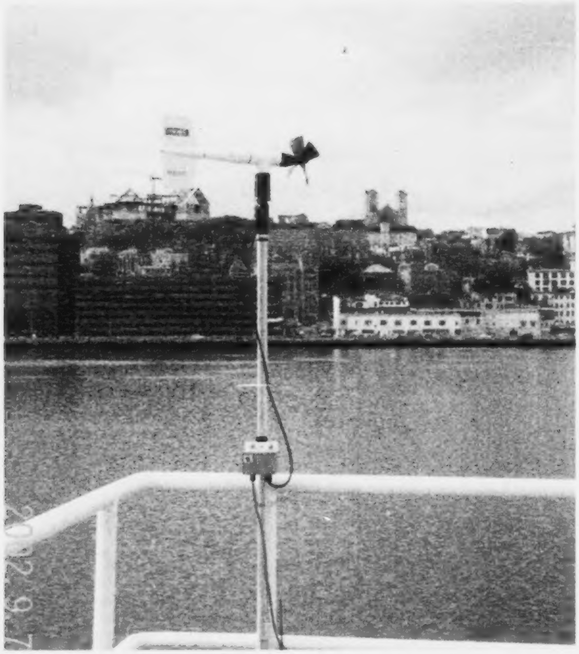


View of winch showing drums and brake release handle

Capacitance wave probe positioned in lifeboat splashdown zone

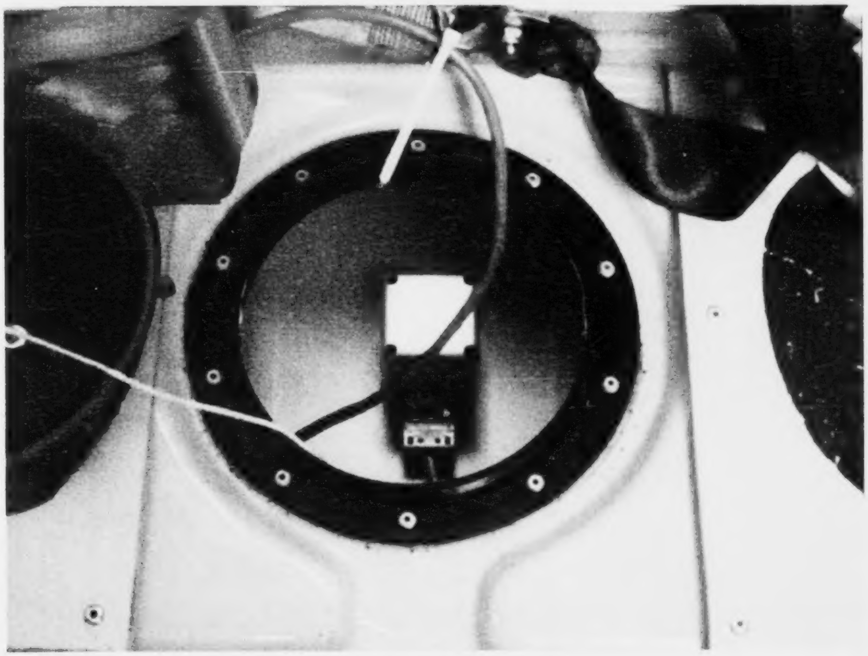


Yo-yo pot positioned to monitor winch drum rotation and fall wire payout



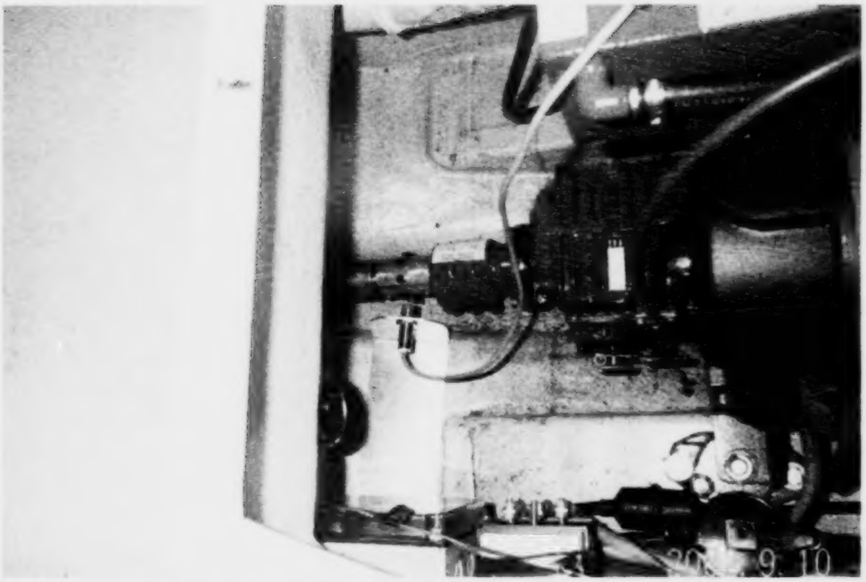
Anemometer to monitor wind speed and direction

Portable shelter for shore-side PC, video recorders and other data acquisition system components



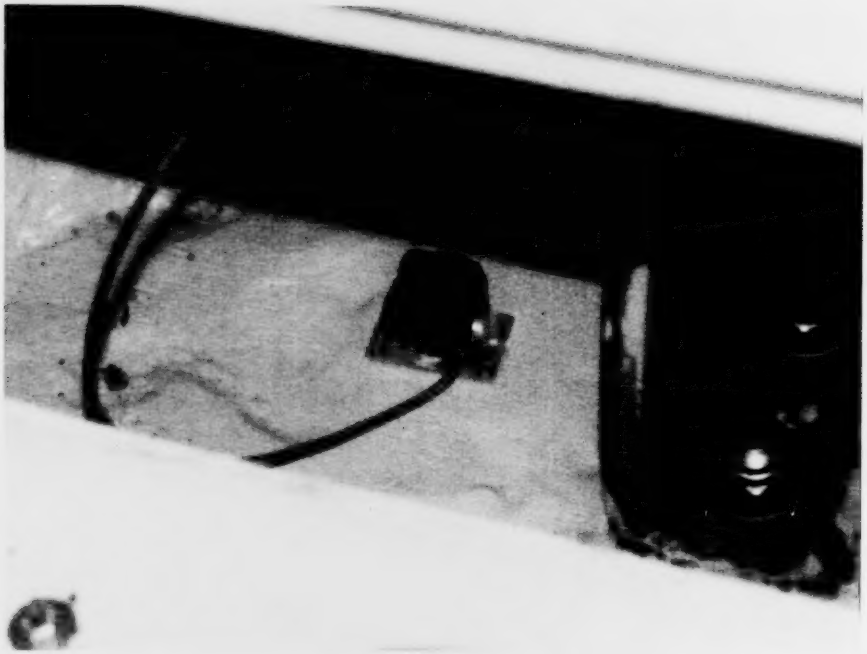
Motion pack mounted at CG of lifeboat

View of port cover providing access to locker where motion pack was installed

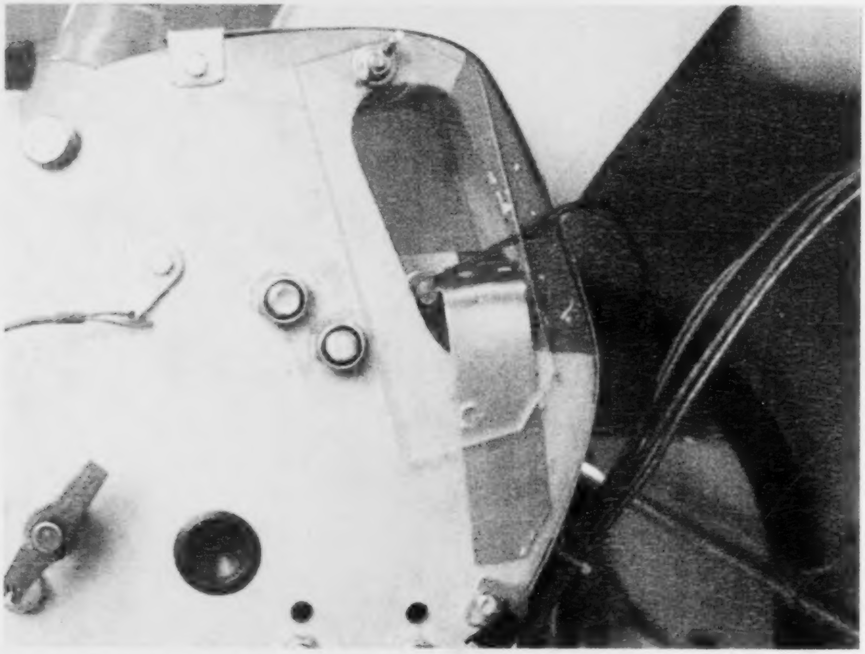


View inside lifeboat engine compartment showing propeller shaft RPM sensor

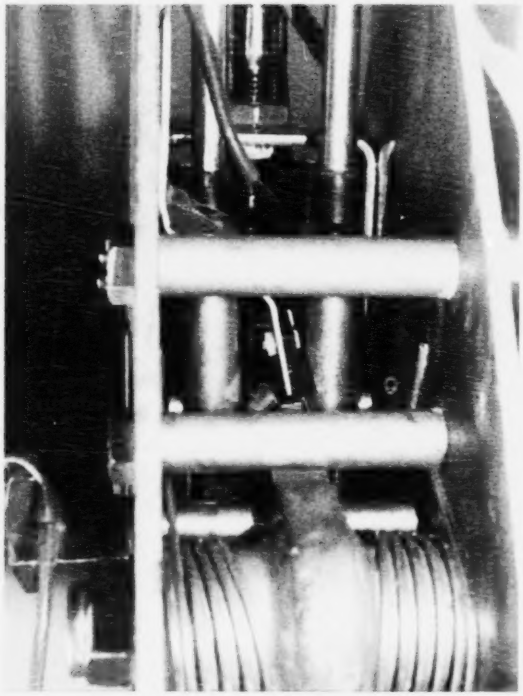
View of lifeboat stern showing yo-yo pot for monitoring rudder angle, accelerometer for vertical accelerations and inclinometers for pitch and roll



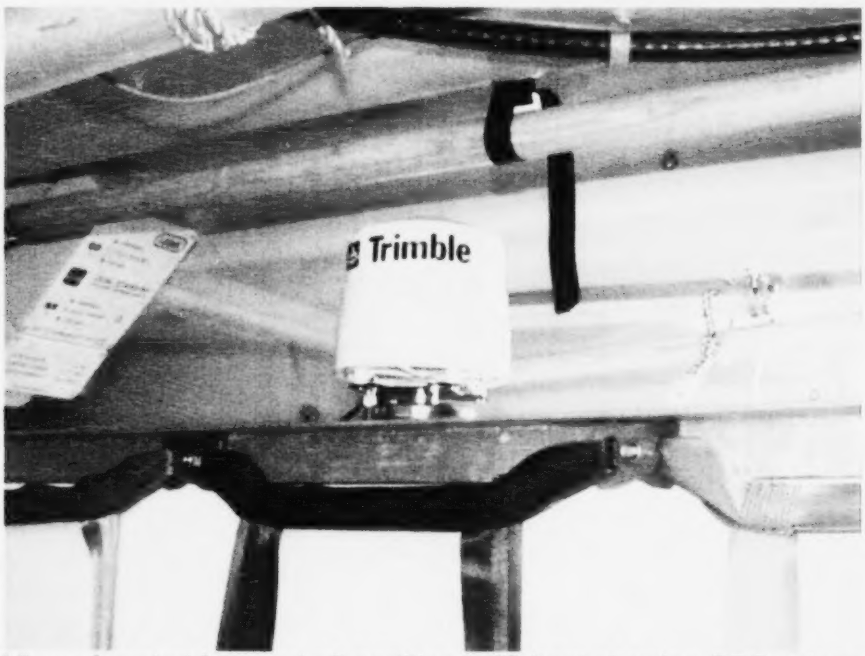
Accelerometer mounted in bow of boat to monitor vertical accelerations



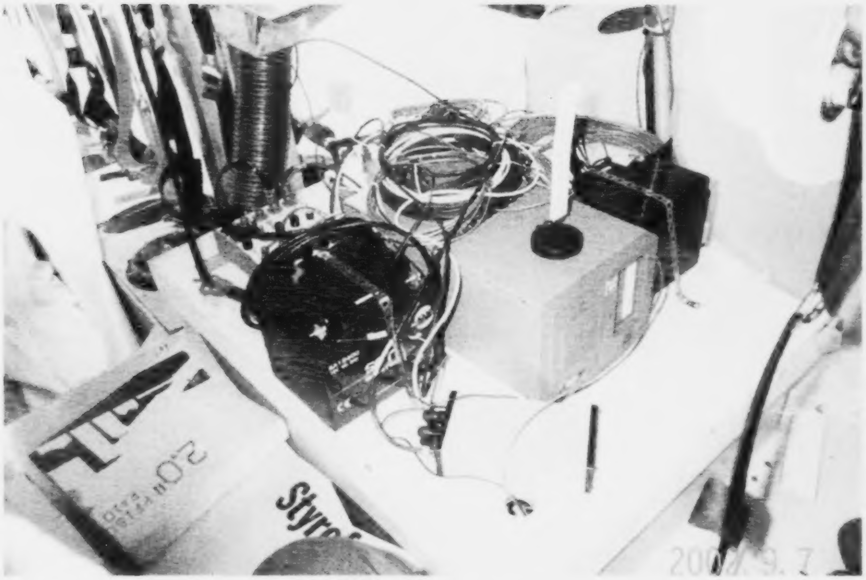
View of release gear showing magnetic switch to monitor hydrostatic interlock indicator and lifeboat water entry



View of release gear showing magnetic switch to monitor operation of the release gear handle

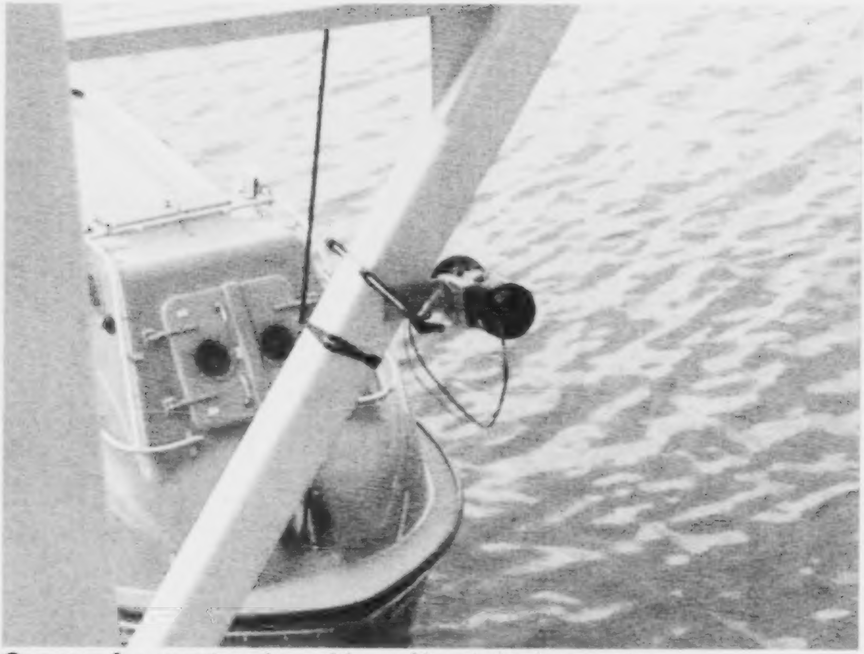


View of central fore-and-aft partition in lifeboat showing GPS antenna position



View of lifeboat engine cover mounting position for batteries, signal conditioning and power "boards", lifeboat PC (industrial 12 v), 802.11b wireless antenna and GPS receiver.

Alternate view of lifeboat data acquisition system components


Camera for quarter view video of boat deployment

Appendix B

Sensor Calibrations

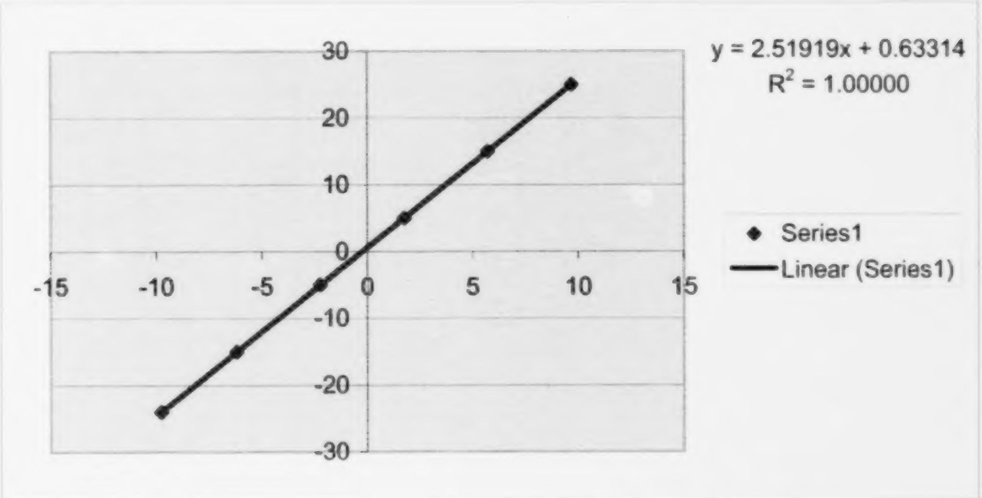
Lifeboat Side Ch. 00
X Rate, Motion Pak

S/N 0326

Scale Factor 50.363 mV/deg/s

Universal Source 169644

Deg/second	injected voltage, mV	Output, Volts
25	1259.075	9.672
15	755.445	5.703
5	251.815	1.734
-5	-251.815	-2.236
-15	-755.445	-6.205
-24	-1208.712	-9.779



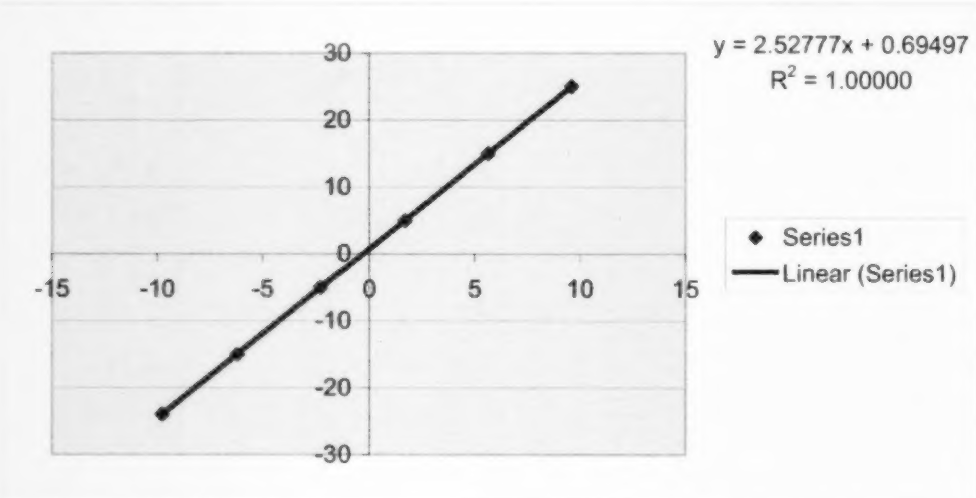
Lifeboat Side Ch. 01
Y Rate, Motion Pak

S/N 0326

Scale Factor 50.221 mV/deg/s

Universal Source 169644

Deg/second	injected voltage, mV	Output, Volts
25	1255.525	9.615
15	753.315	5.659
5	251.105	1.704
-5	-251.105	-2.253
-15	-753.315	-6.21
-24	-1205.304	-9.769



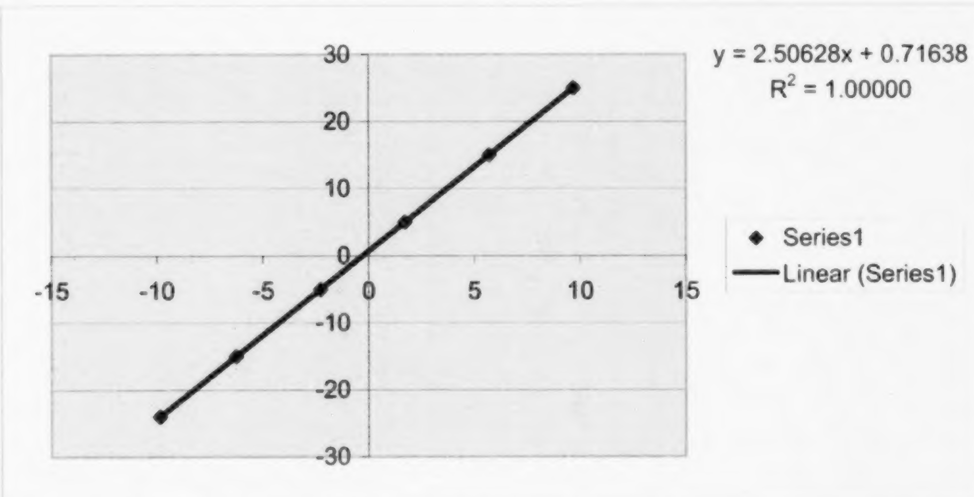
Lifeboat Side Ch. 02
Z Rate, Motion Pak

S/N 0326

Scale Factor 49.926 mV/deg/s

Universal Source 169644

Deg/second	injected voltage, mV	Output, Volts
25	1248.15	9.689
15	748.89	5.7
5	249.63	1.708
-5	-249.63	-2.281
-15	-748.89	-6.27
-24	-1198.224	-9.862

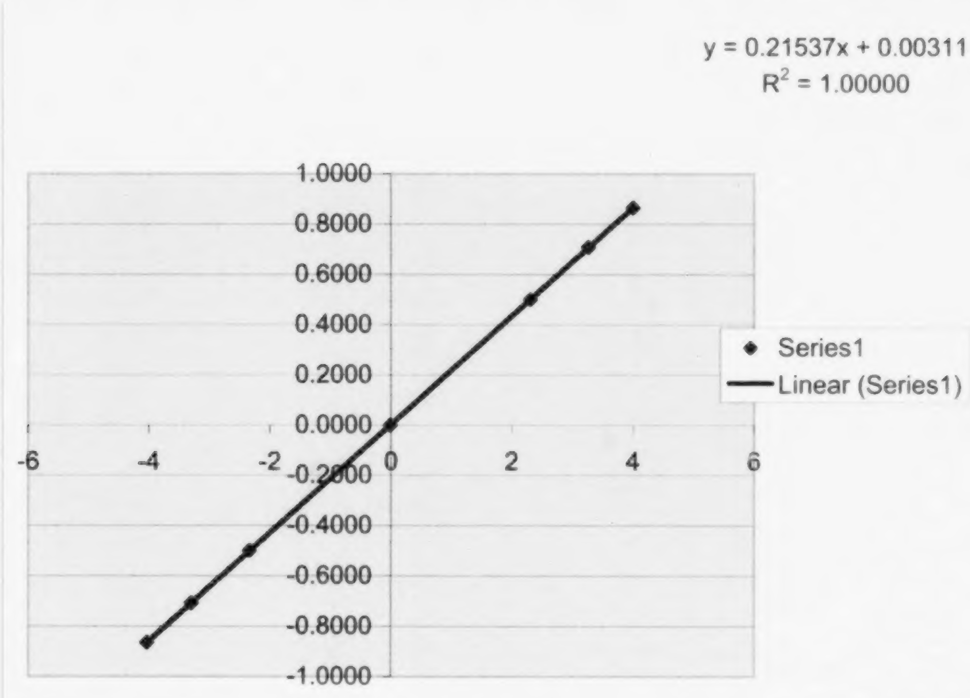


Lifeboat Side Ch. 03
X Accel, Motion Pak

S/N 0326

Gravity 1

Angle	Sin(angle)	Acceleration	Voltage
0	0	0.0000	-0.011
29.994	0.499909307	0.4999	2.309
45.016	0.707304215	0.7073	3.267
59.9	0.865151421	0.8652	4.002
-59.9	-0.865151421	-0.8652	-4.033
-45.016	-0.707304215	-0.7073	-3.297
-29.994	-0.499909307	-0.4999	-2.338

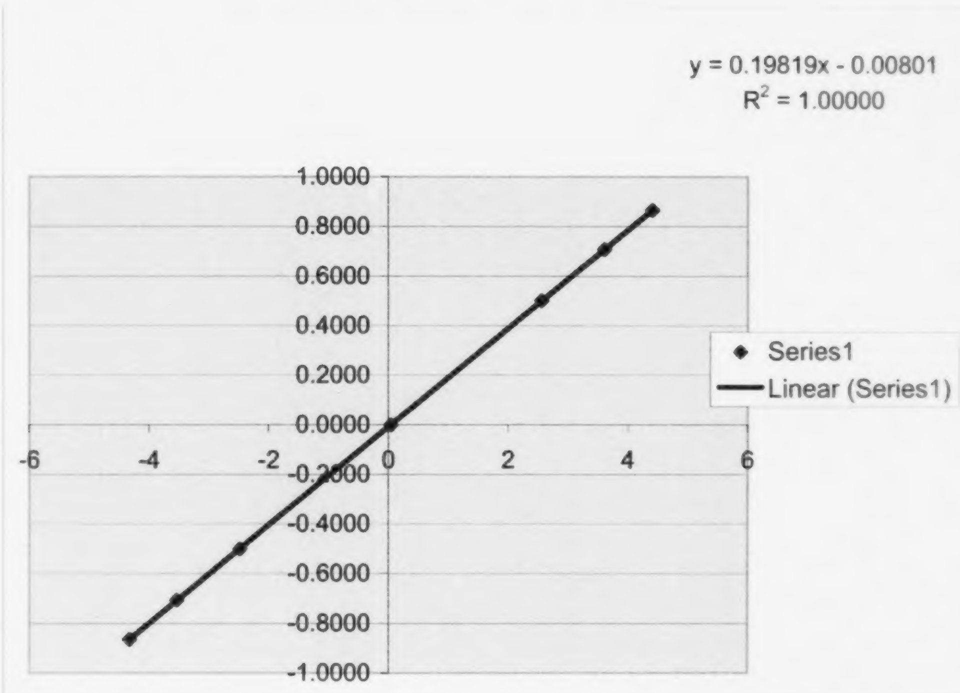


Lifeboat Side Ch. 04
Y Accel, Motion Pak

S/N 0326

Gravity 1

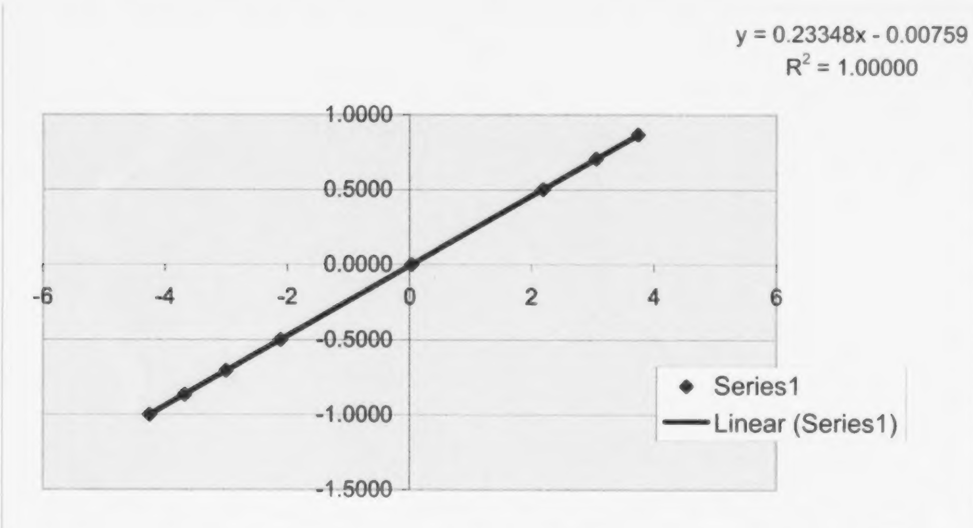
Angle	Sin(angle)	Acceleration	Voltage
0	0	0.0000	0.041
29.994	0.499909307	0.4999	2.562
45.016	0.707304215	0.7073	3.609
59.9	0.865151421	0.8652	4.406
-59.9	-0.865151421	-0.8652	-4.323
-45.016	-0.707304215	-0.7073	-3.534
-29.994	-0.499909307	-0.4999	-2.478



Lifeboat Side Ch. 05
Z Accel, Motion Pak

Gravity 1

wedge	Angle	Sin(angle)	Acceleration	Voltage
0	90	-1	-1.0000	-4.253
29.994	60.006	-0.866077759	-0.8661	-3.679
45.016	44.984	-0.706909292	-0.7069	-2.997
59.9	30.1	-0.501510737	-0.5015	-2.111
90	0	0	0.0000	0.036
-59.9	-30.1	0.501510737	0.5015	2.188
-45.016	-44.984	0.706909292	0.7069	3.056
-29.994	-60.006	0.866077759	0.8661	3.737

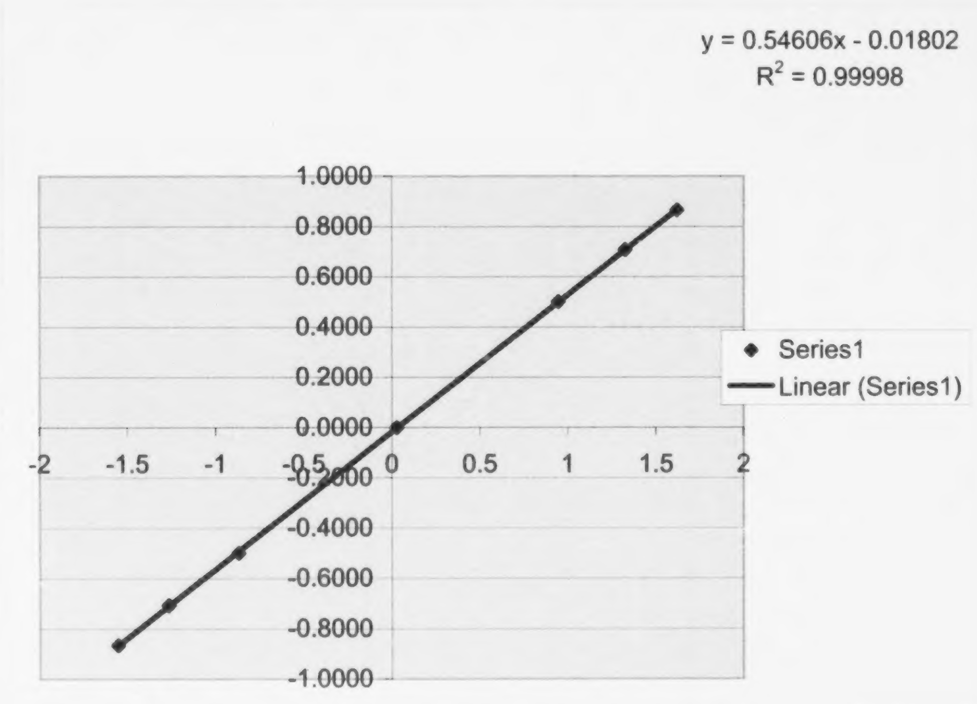


Lifeboat Side Ch. 08
Stern Accels

S/N 4076

Gravity 1

Angle	Sin(angle)	Acceleration	Voltage
0	0	0.0000	0.029
29.994	0.499909307	0.4999	0.946
45.016	0.707304215	0.7073	1.326
59.9	0.865151421	0.8652	1.621
-59.9	-0.865151421	-0.8652	-1.555
-45.016	-0.707304215	-0.7073	-1.266
-29.994	-0.499909307	-0.4999	-0.87

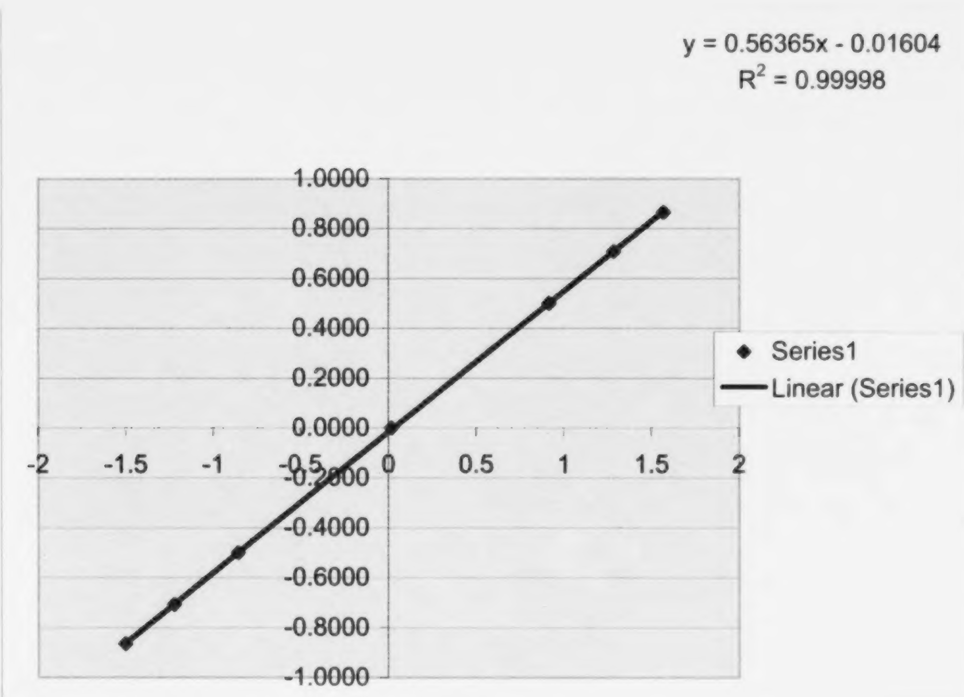


Lifeboat Side Ch. 09
Bow Accel

S/N 784

Gravity 1

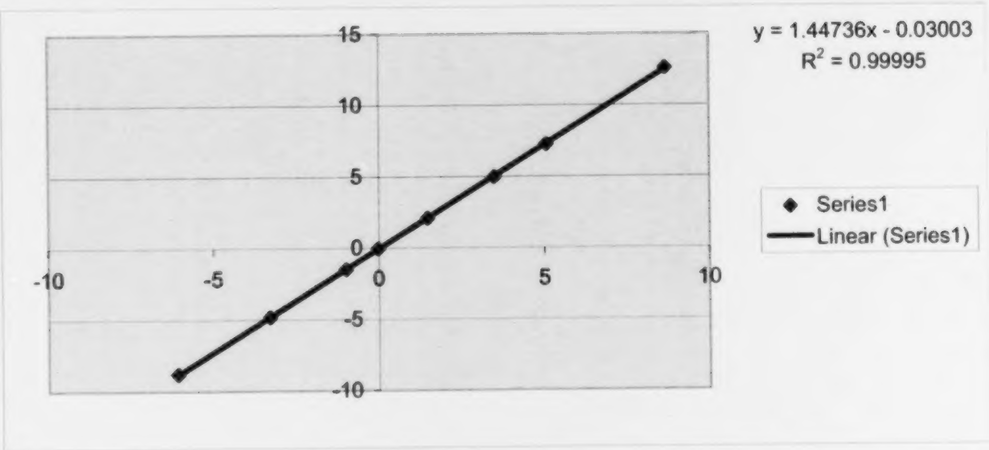
Angle	Sin(angle)	Acceleration	Voltage
0	0	0.0000	0.0162
29.994	0.499909307	0.4999	0.916
45.016	0.707304215	0.7073	1.284
59.9	0.865151421	0.8652	1.568
-59.9	-0.865151421	-0.8652	-1.503
-45.016	-0.707304215	-0.7073	-1.224
-29.994	-0.499909307	-0.4999	-0.858



Lifeboat Side Ch.12
Pitch Incl 15 degs

S/N 38566

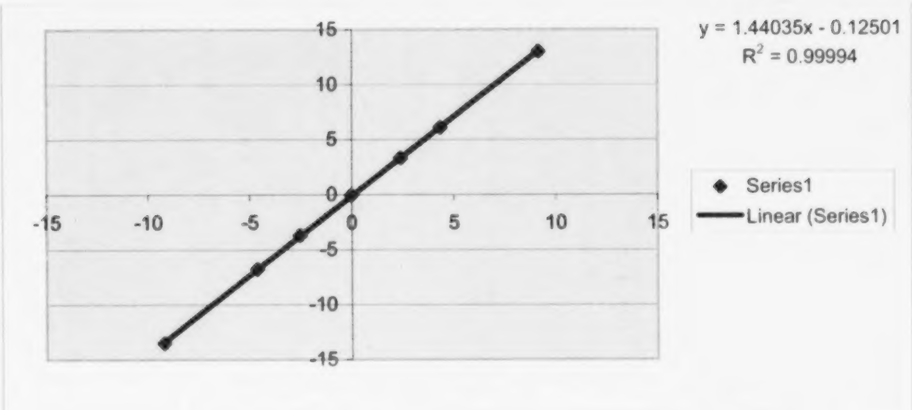
Angle, degrees	Output, Volts
-0.05	-0.024
-1.49	-1.002
-4.81	-3.308
-8.8	-6.082
2.09	1.474
4.98	3.507
7.25	5.064
12.6	8.669



Lifeboat Side Ch.13
Roll Incl 15 degs

S/N 38567

Angle, degrees	Output, Volts
-0.06	-0.015
-3.72	-2.541
-6.77	-4.637
-13.5	-9.218
3.31	2.392
6.09	4.337
13	9.144



Lifeboat Side Ch. 07
Rudder Angle

10" Yo-Yo Pot

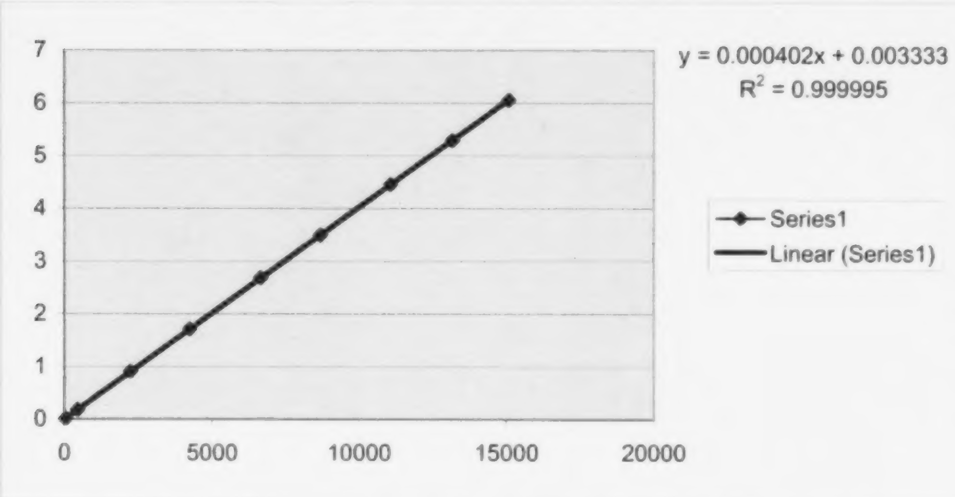
S/N A55549

Angle	Output

Not Cal

Shore Side Ch. 00

	volts mts	newtons	Voltage		Error(N)	Error (%)
offset (0 load)	0.015	37.5	0.009	1.48107	-36.01893	-0.405%
100lbf	0.177	442.5	0.18	189.4699	-253.0301	-2.844%
504lbf	0.897	2242.5	0.911	993.0948	-1249.405	-14.045%
955lbf	1.7	4250	1.714	1875.873	-2374.127	-26.688%
1498lbf	2.666	6665	2.684	2942.242	-3722.758	-41.848%
1954lbf	3.478	8695	3.5	3839.312	-4855.688	-54.583%
2491lbf	4.433	11082.5	4.457	4891.39	-6191.11	-69.594%
2959lbf	5.265	13162.5	5.292	5809.347	-7353.153	-82.657%
3389lbf	6.03	15075	6.056	6649.251	-8425.749	-94.714%

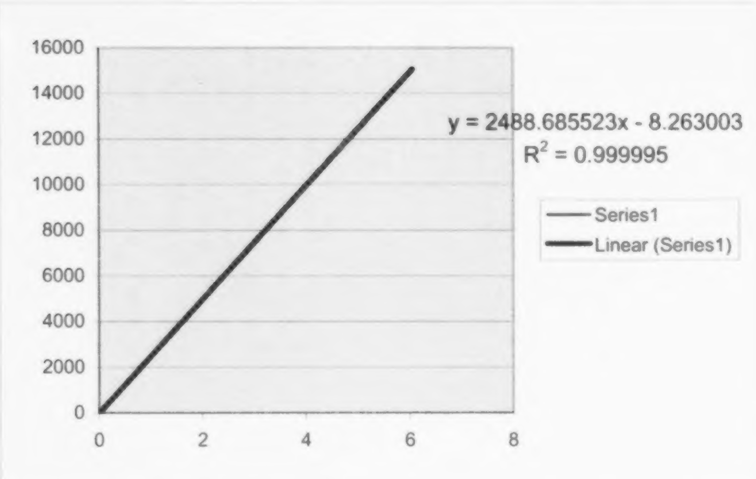


Shore Side Ch. 00

Dec 20 02

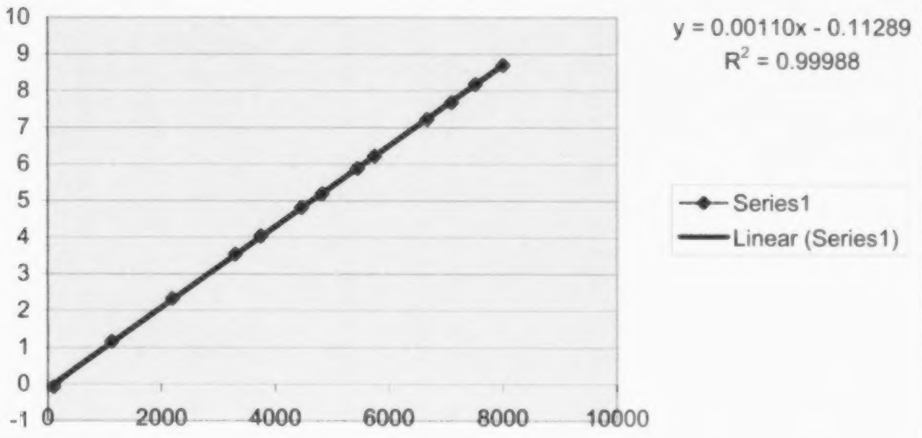
y = 2488.685523x - 8.263003
R2 = 0.999995

0.009	37.5
0.18	442.5
0.911	2242.5
1.714	4250
2.684	6665
3.5	8695
4.457	11082.5
5.292	13162.5
6.056	15075



Shore Side Ch. 01

	volts mts	newtons	Voltage	Cal Load(N)	Error(N)	Error (%)
offset (0 load)	0.04	100	-0.082	28.60	-71.40436	
252lbf	0.45	1125	1.164	1159.13	34.12968	0.384%
492lbf	0.876	2190	2.332	2218.89	28.89194	0.325%
740lbf	1.318	3295	3.54	3314.95	19.94742	0.224%
1003lbf	1.785	4462.5	4.813	4469.98	7.47939	0.084%
1222lbf	2.176	5440	5.883	5440.82	0.823233	0.009%
1498lbf	2.666	6665	7.223	6656.65	-8.353636	-0.094%
1689lbf	3.006	7515	8.171	7516.80	1.795863	0.020%
1799lbf	3.201	8002.5	8.7	7996.77	-5.726199	-0.064%
1596lbf	2.84	7100	7.682	7073.11	-26.88885	-0.302%
1290lbf	2.297	5742.5	6.22	5746.59	4.093678	0.046%
1083lbf	1.928	4820	5.19	4812.04	-7.956938	-0.089%
840lbf	1.496	3740	4.034	3763.17	23.16878	0.260%

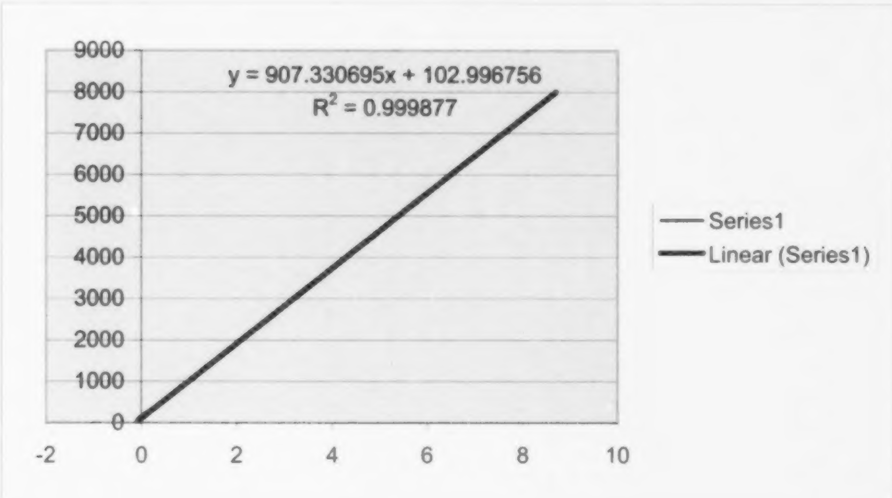


Shore Side Ch. 01

dec20 02

y = 907.330695x + 102.996756
R2 = 0.999877

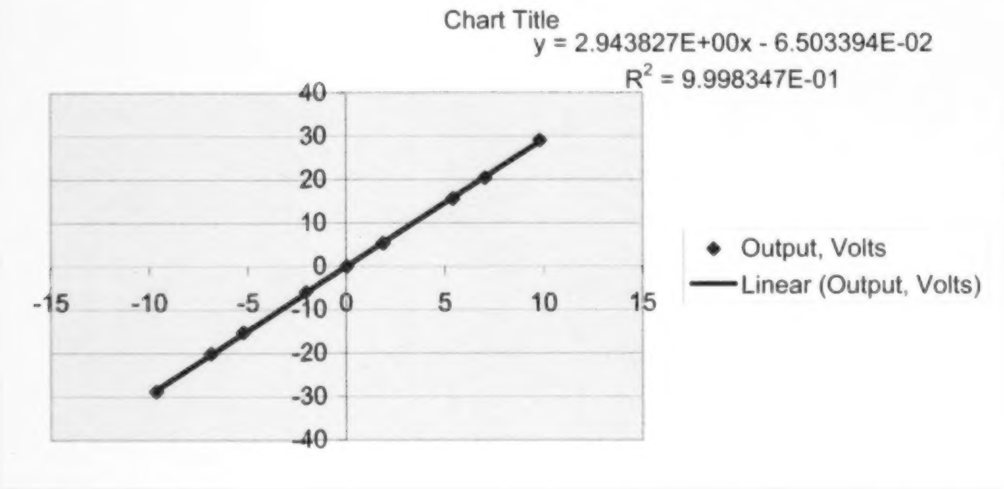
-0.082	100
1.164	1125
2.332	2190
3.54	3295
4.813	4462.5
5.883	5440
7.223	6665
8.171	7515
8.7	8002.5
7.682	7100
6.22	5742.5
5.19	4820
4.034	3740



Shore Side Ch. 03

RAM Position, Inclinometer 30 degrees S/N 43258

Angle, Degrees	Output, Volts
0	0.036
-5.91	-2.039
-15.2	-5.24
-20.1	-6.876
-28.8	-9.657
5.29	1.876
15.6	5.405
20.4	7.022
29.1	9.789
0	0.034

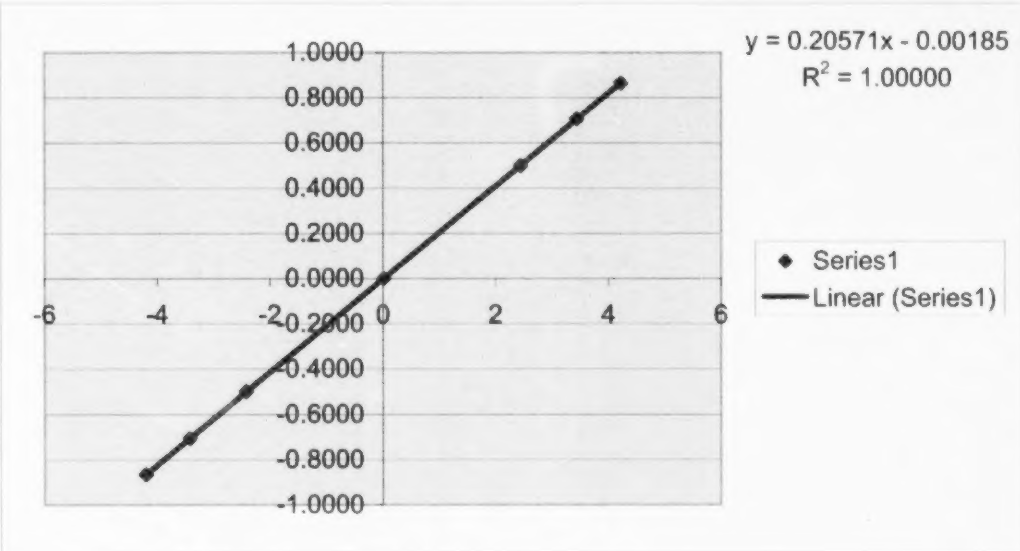


Shore Side Ch. 04 (original)

X Accels

Gravity 1

Angle	Sin(Angle)	Acceleration	Voltage
0	0	0.0000	0.011
29.994	0.499909307	0.4999	2.441
45.016	0.707304215	0.7073	3.44
59.9	0.865151421	0.8652	4.219
-59.9	-0.865151421	-0.8652	-4.202
-45.016	-0.707304215	-0.7073	-3.421
-29.994	-0.499909307	-0.4999	-2.425

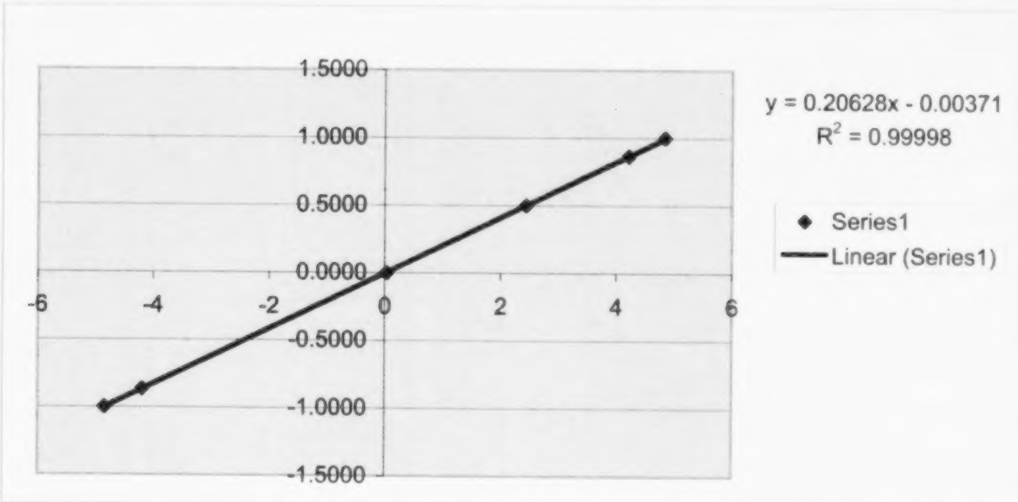


Shore Side Ch. 04 (replacement)

X Accels

Gravity 1

Angle (Theoretical)	Angle (Measured)	Sin(Measured Angle)	Acceleration	Voltage
0	0.04	0.000698132	0.0007	0.028
60	59.8	0.864274802	0.8643	4.217
90	89.9	0.999998477	1.0000	4.84
150	150.1	0.49848774	0.4985	2.44
180	180.1	-0.001745328	-0.0017	0.03
240	240	-0.866025404	-0.8660	-4.186
270	269.9	-0.999998477	-1.0000	-4.84

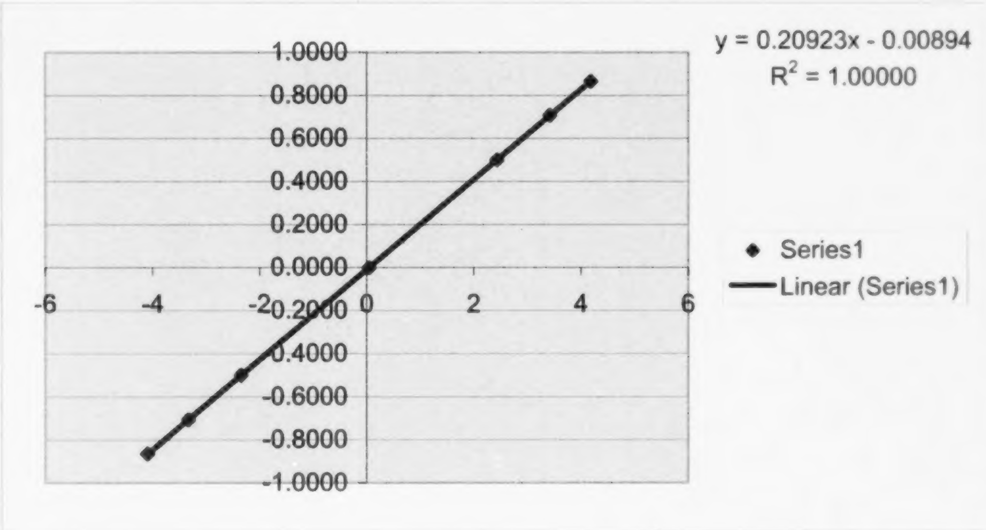


Shore Side Ch. 05 (original)

Y Accels

Gravity 1

Angle	Sin(angle)	Acceleration	Voltage
0	0	0.0000	0.041
29.994	0.499909307	0.4999	2.435
45.016	0.707304215	0.7073	3.419
59.9	0.865151421	0.8652	4.18
-59.9	-0.865151421	-0.8652	-4.094
-45.016	-0.707304215	-0.7073	-3.332
-29.994	-0.499909307	-0.4999	-2.35

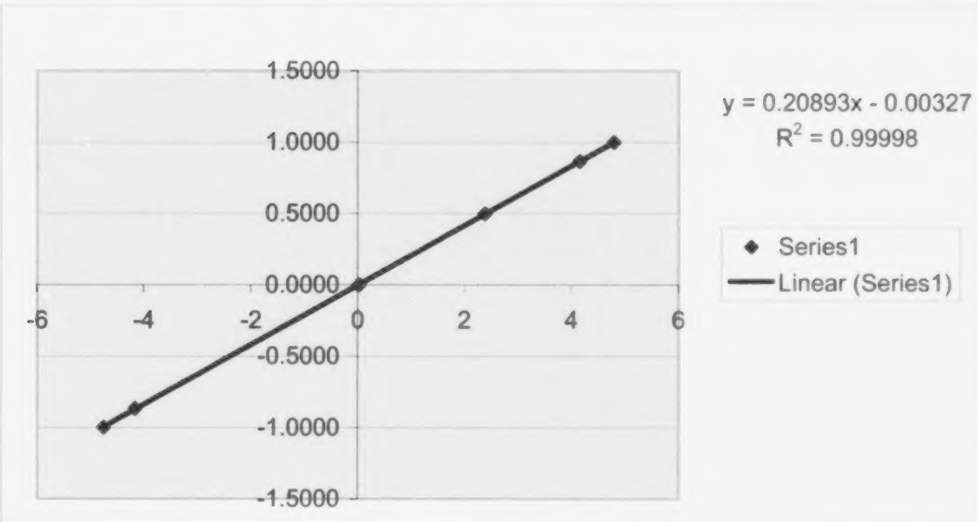


Shore Side Ch. 05 (replacement)

Y Accels

Gravity 1

Angle (Theoretical)	Angle (Measured)	Sin(Measured Angle)	Acceleration	Voltage
0	0.04	0.000698132	0.0007	0.033
60	59.8	0.864274802	0.8643	4.159
90	89.9	0.999998477	1.0000	4.796
150	150.1	0.49848774	0.4985	2.389
180	180.1	-0.001745328	-0.0017	0.015
240	240	-0.866025404	-0.8660	-4.16
270	269.9	-0.999998477	-1.0000	-4.75

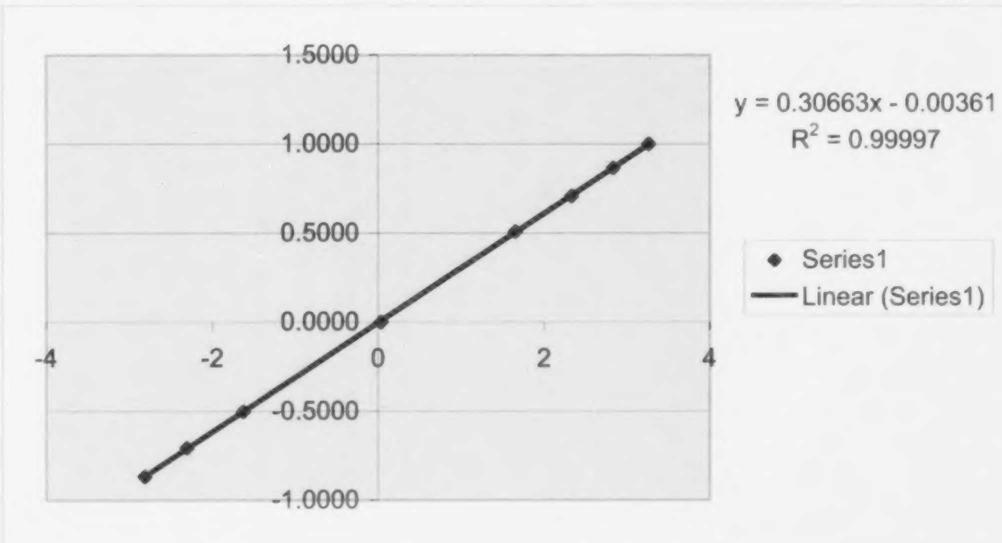


Shore Side Ch. 06 (original)

X Accels

Gravity 1

wedge	Angle	Sin(angle)	Acceleration	Voltage
0	90	1	1.0000	3.263
29.994	60.006	0.866077759	0.8661	2.833
45.016	44.984	0.706909292	0.7069	2.332
59.5	30.5	0.507538363	0.5075	1.653
90	0	0	0.0000	0.038
-59.9	-30.1	-0.501510737	-0.5015	-1.627
-45.016	-44.984	-0.706909292	-0.7069	-2.305
-29.994	-60.006	-0.866077759	-0.8661	-2.812

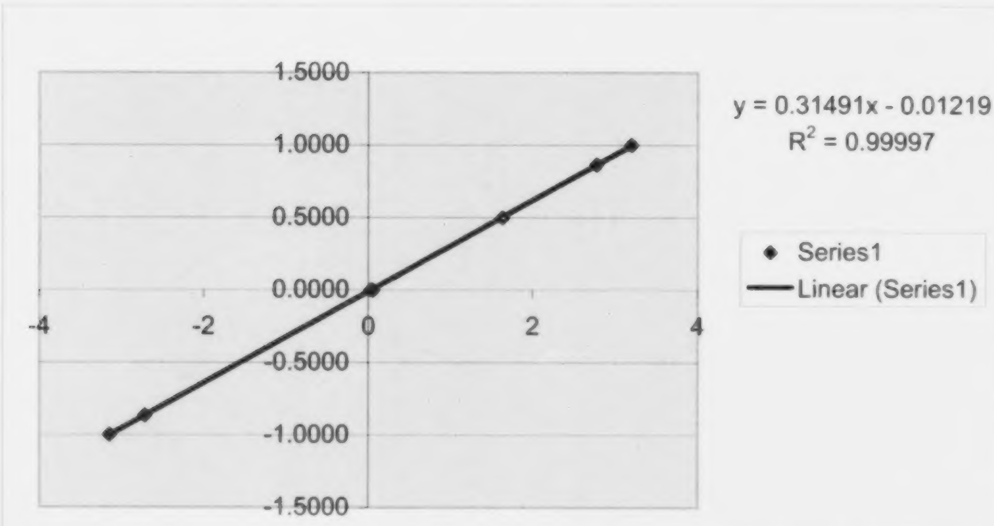


Shore Side Ch. 06 (replacement)

Z Accels

Gravity 1

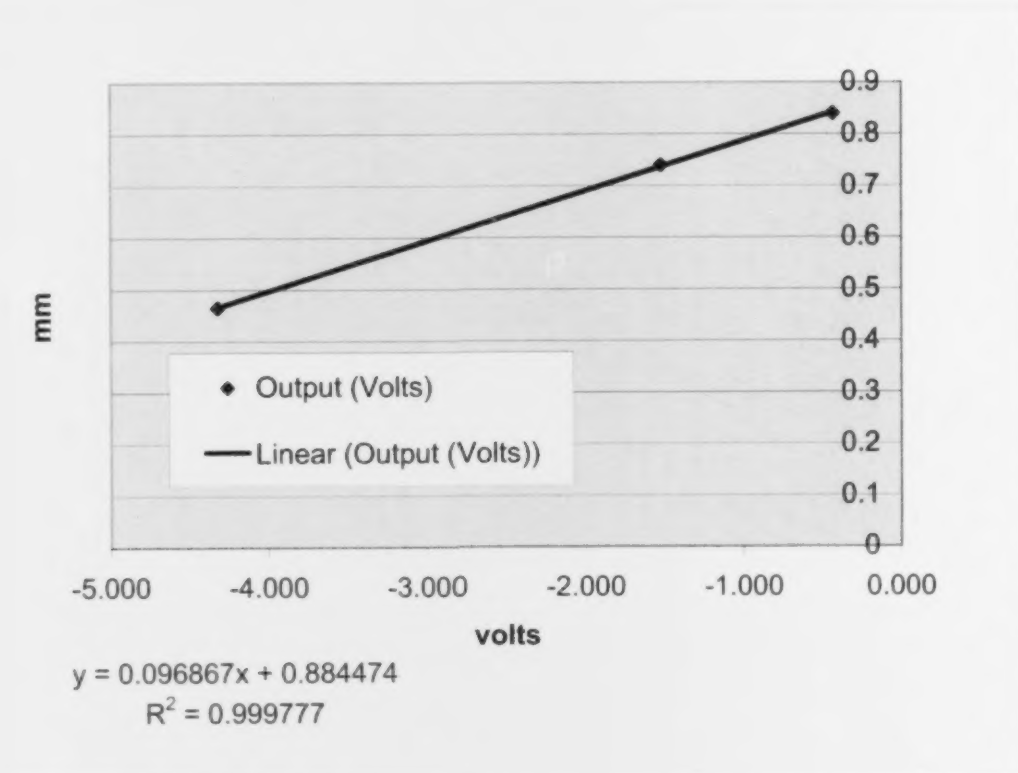
Angle (Theoretical)	Angle (Measured)	Sin(Measured Angle)	Acceleration	Voltage
0	0.04	0.000698132	0.0007	0.033
60	59.8	0.864274802	0.8643	2.779
90	89.9	0.999998477	1.0000	3.2
150	150.1	0.49848774	0.4985	1.636
180	180.1	-0.001745328	-0.0017	0.056
240	240	-0.866025404	-0.8660	-2.714
270	269.9	-0.999998477	-1.0000	-3.145



Shore Side Ch. 08 Wave Probe - Brancker Box

Height (m)	Output (Volts)
0.465	-4.321
0.74	-1.525
0.84	-0.435

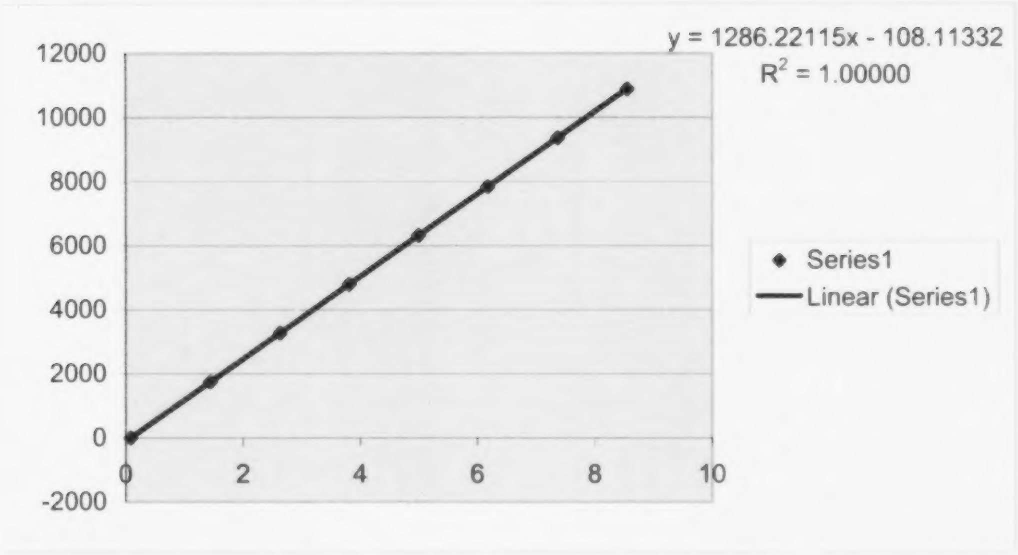
0 -8.462



Shore Side Ch. 10

Yoyopot - Payout displacement

Displacement (mm)	Output (V)
0	0.084
1744	1.44
3268	2.626
4792	3.811
6316	4.994
7840	6.175
9364	7.364
10888	8.552

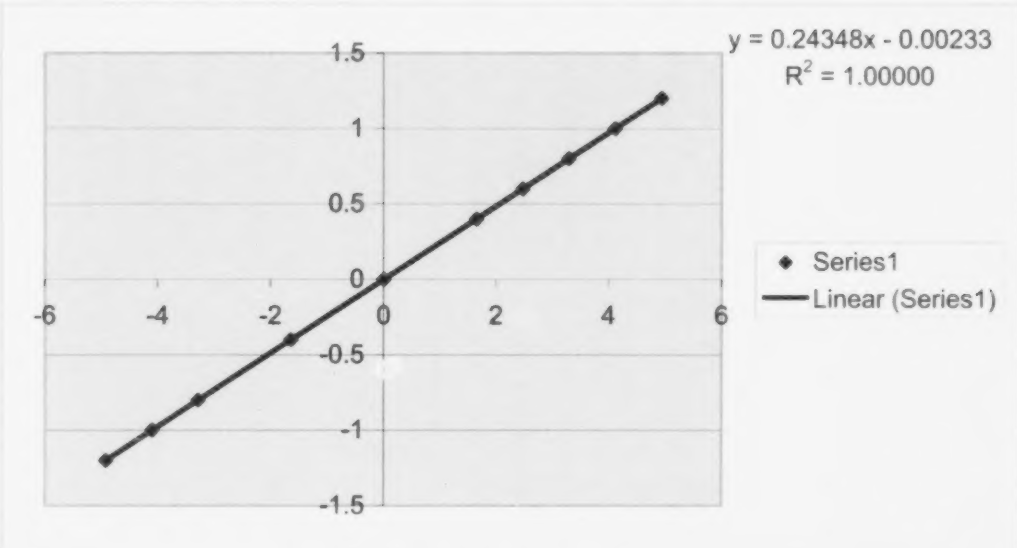


Shore Side Ch. 11

Yoyo pot - payout rate

sensitivity 8.221 mV/m/s

Input (V)	Rate (m/s)	Output (V)
-9.8652	-1.2	-4.919
-8.221	-1	-4.098
-6.5768	-0.8	-3.276
-3.2884	-0.4	-1.633
0	0.00	0.010
3.2884	0.40	1.652
4.9326	0.60	2.474
6.5768	0.80	3.295
8.221	1.00	4.116
9.8652	1.20	4.939



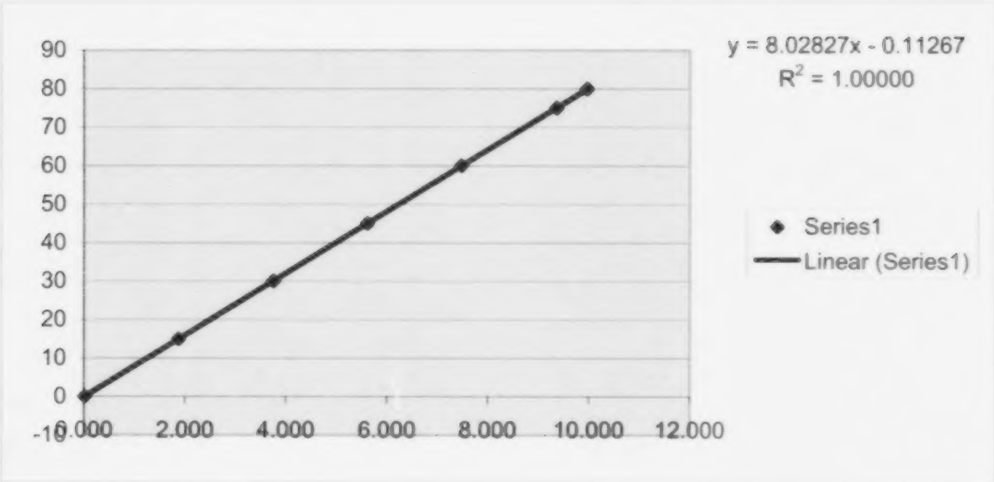
Shore Side Ch. 12

anemometer - wind speed

max speed = 180 km/h

Input (V)	Speed (km/h)	Output (V)
0.000	0	0.012
0.083	15	1.880
0.167	30	3.758
0.250	45	5.620
0.333	60	7.482
0.417	75	9.366
0.444	80	9.971

factory cal done with extension cable

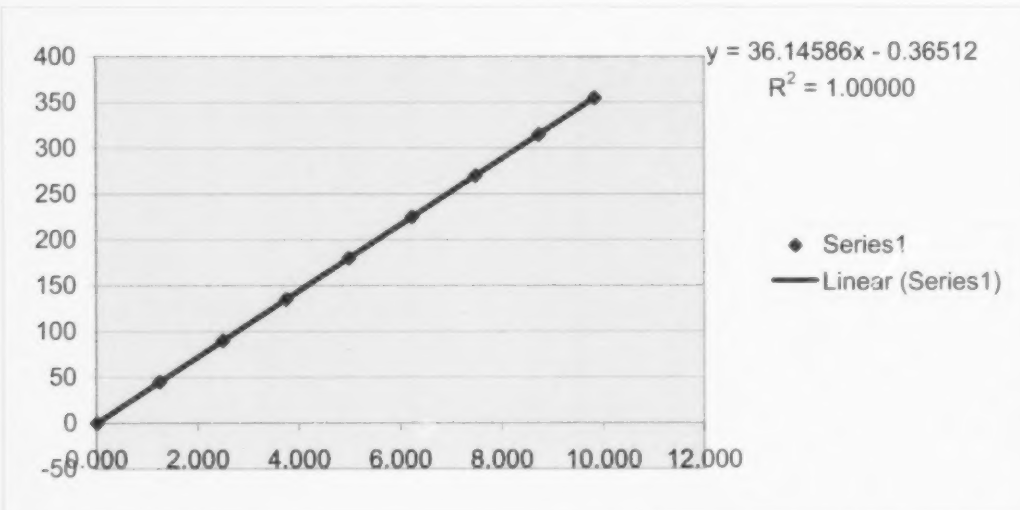


Shore Side Ch. 13

anemometer - wind dir

f.s. o/p @ 355 deg= 0.986 V
Max dir. = 355 deg

Input (V)	Angle (deg)	Output (V)
0.000	0	0.010
0.125	45	1.255
0.250	90	2.500
0.375	135	3.745
0.500	180	4.990
0.625	225	6.235
0.750	270	7.480
0.875	315	8.725
0.986	355	9.831



Appendix C

Data Acquisition System Description

IOT's Signal Conditioner Specifications

The signal conditioners used for project 874 (full-scale lifeboat trials) were designed by IOT. Each of these signal conditioners may provide support for up to 16 transducers.

A simplified list of signal conditioner functions:

- Provide excitation for a transducer.
- Filter an incoming analog signal.
- Amplify an incoming analog signal.
- Attenuate an incoming analog signal.

Excitation

Unipolar or bipolar excitation modes are available. Each channel has a red LED on the exterior of the case that shows what mode the channel is set for. Unipolar is available in the range of +4 V to +12 V DC. Bipolar excitation is available as ±15 V DC. You may choose either of these via a jumper setting inside the enclosure. A potentiometer, which is located inside the case, provides for adjustments in the range of 4 to 12 V. In most cases the excitation is set to 10 V or ±15 V. For example, 10 V would be used in for most loadcells and ±15 V would be used for accelerometers or inclinometers.

Filtering

Like the excitation jumper setting, there is also a jumper to select if the incoming analog signal will be filtered or not. Selecting a jumper setting of filtered allows the user to choose a value of 10, 50, 100, or 200 Hz as the cutoff frequency.

Amplification

Amplification (gain) for each channel may be selected in one of two ways. The easiest method is to select the amount of gain you need to provide via a jumper. This jumper may be used to select gain settings of 2, 10, 150, or 250. In many cases one of these values will provide the adequate amount of gain for the incoming signal. The other way to select gain is by placing the jumper from the previous method in the position for a gain of 2, which is also the programmed gain position, and then placing a resistor in the appropriate socket. Once the amount of gain that is required, is calculated, you may use the equation $R_G = 80000/(G - 2)$ to calculate the value of the resistor that needs to be used to attain your desired amplification. In the equation G is the required gain and R_G is the calculated resistor value. Two sets of sockets are provided for resistors. This simply allows you to use 2 resistors instead of one to make up the required resistor value. A maximum value of gain that may be used with this signal conditioner is 3500.

Attenuation

An attenuation jumper is also available for each channel. This jumper allows for a signal attenuation of 4 (divide by 4).

PROJECT NAME: FULL SCALE LIFEBOAT TRIAL

PROJECT NUMBER: #874

SIGNAL CONDITIONER: **#5** (LIFEBOAT SIDE)

DATE: 27-AUGUST-2002

CHAN #	DESCRIPTION/DEVICE	SERIAL #	BARCODE	RANGE	FILTER	GAIN	GAIN RESISTOR
00	X Rate MP	0326	207183		10Hz		
01	Y Rate MP	0326	207183		10Hz		
02	Z Rate MP	0326	207183		10Hz		
03	X Accel MP	0326	207183		10Hz		
04	Y Accel MP	0326	207183		10Hz		
05	Z Accel MP	0326	207183		100Hz		
06	Engine RPM Tach				10Hz		
07	Rudder Angle Yo-Yo Pot 10 in	A55549	169628	10 in	10Hz	1	20K+20K+Atten
08	Stern Accel Shock Load	4076	018648		100Hz		
09	Bow Accel Shock Load	784	A10362		100Hz		
10	Splash Down Switch (magnetic Switch)				10Hz		
11	Blocks Open Switch				10Hz		
12	Pitch Inclinometer +/-14.5	38566	169549		10Hz	2	Prog
13	Roll Inclinometer +/-14.5	38567	169550		10Hz	2	Prog.
14							
15							

TELEMETRY CHANNEL ASSIGNMENT

PROJECT NAME: FULL SCALE LIFEBOAT TRIAL

PROJECT NUMBER: #874

SIGNAL CONDITIONER: **#7** (SHORE SIDE)

DATE: 27-AUGUST-2002

CHAN #	DESCRIPTION/DEVICE	SERIAL #	BARCODE	RANGE	FILTER	GAIN	GAIN RESISTOR
00	Tag Line Loadcell S-Type (water proof)		A10397	1K	10Hz	320	267
01	Bollard Loadcell S-Type (water proof)		A11175	2K	10Hz	320	267
02	Ram Pressure, pressure transducer				10Hz		
03	Ram Position, Inclinometer +/-30°	43258	018592		10Hz	2	Prog
04	X Accel	4080	018651		100Hz		
05	Y Accel	4078	018650		100Hz		
06	Z Accel	4077	018649		100Hz		
07	Winch Brake Release Switch	NA	NA	NA	10Hz		
08	Wave Height	7235	207244	2m	10Hz	2	Prog.
09					10Hz		
10	Payout Displacement DV 500 in Yo-Yo Pot		168566	500 in	10Hz	1	20K+20K+Atten
11	Payout Velocity 500 in Yo-Yo Pot				10Hz		
12	Wind Speed (RM Young Weather Station)			60 km/h	10Hz	30	2.67K + 150
13	Wind Direction (RM Young Weather Station)			355 degs	10Hz	10	
14							
15							

Description of OSSC Data Acquisition Software

September 25, 2002

The OSSC Data Acquisition system consists of two computers – one on the shore platform and one on the lifeboat – that are connected via a wireless network. Both machines have a Windows operating system and both are equipped with DaqBoard 2000 hardware for acquisition of analog channels. The lifeboat computer is also connected to a Trimble DSM 212 DGPS receiver, which is used to acquire position data by NMEA sentences. Time is synchronized between the two computers by Tardis time synchronization software.

The operator interacts with the shore platform system, from which he remotely connects to the lifeboat system by using PCAnywhere. At the beginning of each experiment the operator remotely connects to the lifeboat computer and starts data acquisition. He then switches off PCAnywhere so that the lifeboat computer is dedicated entirely to data acquisition. He then starts the acquisition on the shore platform computer and the run commences. At the end of the run the operator stops acquisition on the shore platform computer and then remotely connects to the lifeboat computer system and stops acquisition on it as well. At this instance the lifeboat may be outside the range of the wireless network, so the operator may have to wait for the lifeboat to return closer to the shore platform before he can make the remote connection. Once the operator has connected to the lifeboat computer and stopped acquisition he may transfer the new file to the shore computer and then archive all data on compact disc.

Key software components on the shore platform computer are:

- PCAnywhere: software to enable remote control of the lifeboat computer.
- ShorebaseLogger.exe: custom software for data acquisition.
    - 100 Samples per second, analog channels only.
- ShorebaseCal: custom software for data post-calibration.
- DaqView and Microsoft Excel: for calibration procedure and data viewing.
- Tardis: time synchronization software, master.

Key software components on the lifeboat computer are:

- PCAnywhere: software to enable remote control from the shore platform computer.
- LifeboatLogger.exe: custom software for data acquisition.
    - 100 Samples per second analog channels,
    - 100 samples per second counter/timer channels,
    - 10 samples per second DGPS position data via NMEA sentences.
- LifeboatCal.exe: custom software for data post-calibration
- DaqView and Microsoft Excel: for calibration procedure and data viewing.
- Tardis: time synchronization software, slave.

LifeboatLogger.exe

The program LifeboatLogger runs on the lifeboat computer system. It is used to acquire data from analog and counter channels, as well as to parse NMEA sentences sent to the lifeboat computer system from the DGPS unit. LifeboatLogger provides a graphical user-interface that enables the operator to control acquisition. It was written in Microsoft Visual Basic 6.0, and tested for Windows 2000. The LifeboatLogger program uses a programming interface from IOTech to issue commands and receive data from an onboard DaqBoard 2000, and it uses a slave process to acquire data from the peripheral DGPS unit.

The analog data sampling rate is hard coded at 100 samples per second for each of 16 analog channels, for an aggregate analog channel sampling rate of 1600 samples per second. Raw data counts from the Daqboard are recorded. The values are 16 bit unsigned integers where 0 corresponds to bottom of scale and 65535 corresponds to full scale. Additionally, there are two counter channels that are sampled in the same manner as the analog channels. The counter channels represent the number of pulses detected by a sensor on the propeller shaft, and is used to calculate shaft speed. Data is post calibrated and changed to physical units by the LifeboatCal program.

The Trimble DSM 212 DGPS unit transmits NMEA sentences to the serial communications port of the lifeboat acquisition computer at a baud rate of 38400 bps with 8 data bits, 1 stop bit and no parity. A slave program captures and parses these sentences, which may include: GPGLL, GPGGA, GPVHW, GPVTG, GPZDA, and HEHDT sentences, depending on how the DGPS unit is configured. (Note that not all these sentences need be present, only the combination that provides the desired data.) The NMEA sentences give position updates at a rate of 10 per second and contain the following:

- Universal Coordinated Time (UTC),
- Fix Quality Indicator
- UTC of Fix
- Latitude,
- Longitude,
- Course Over Ground (COG),
- Speed Over Ground (SOG)

The slave process acquires and parses the stream of NMEA sentences and makes the data available to the LifeboatLogger program.

LifeboatLogger writes the most recent buffers of data to disc at 1/10 of the sampling rate. The analog and counter data is multiplexed with the position data when it is saved to disc. Since the positional data is acquired at 10 per second and the analog and counter data is acquired at 100 samples per second, the positional data is repeated in the file. Each position fix is repeated ten times for each ten analog and counter samples. The program simply captures whatever data is available at each sampling period, and thus the position data is sampled faster than it changes. The data is written in ASCII format, delimited by commas and spaces to enable the file to be easily read by programs such as Microsoft Excel.

The operator interacts with the LifeboatLogger program through the graphical user interface. He may choose any base file name, to which the LifeboatLogger program will append *_yyyymmddhhmmss.DAT*. For example, if the user inputs a base file name of *test* the resulting data file name may look like *test_20010815155445.DAT*. The date stamp file name is taken at the instant the user presses the Start Acquisition button. Thereby, the data file names will always be unique, decreasing the risk of loosing data by overwriting it.

Notes:

At a sampling rate of 100 Hz the Windows 2000 Task Manager reports 100% CPU usage of the Pentium 233 CPU. However, it appears that the CPU was able to keep up with the data acquisition. At a sampling rate of 500 Hz the Pentium 233 computer became unresponsive and was not able to keep up with the data acquisition.

No other process was run while data was being acquired.

Since LifeboatLogger does not have calibration capabilities the calibration constants were worked out manually via DaqView and Excel. Data was post-calibrated by the program LifeboatCal, and viewed via Excel.

Data is to be post calibrated and converted to physical units. Real-time conversion, calibrating, and plotting capabilities have not been implemented.

LifeboatCal.exe

The program LifeboatCal is used to calibrate and decimate the raw data that is recorded by the LifeboatLogger program. LifeboatCal serves two purposes: it calibrates the raw data and converts it to physical units; and it may also be used to decimate the data so that the large files may be viewed in near real-time via Excel. It produces calibrated data files in ASCII comma-space delimited (.CSV) format.

LifeboatCal requires that the calibration constants be worked out at the beginning of the test program, and saved in an Excel spreadsheet in comma-space delimited format. The spreadsheet file will contain the slope and offset of the linear fit for each column of analog data.

Internally, the data is first converted from counts to units of volts by the following formula:

Volts = (Counts – 32767.5) * 0.00030518

Where Counts = 0 to 65535
Volts = -10 to +10

The calibration is then applied by the formula: y = m(x) + b
Where y = the physical quantity in the desired units
m = the slope of the calibration line
x = the analog value converted to volts
b = the offset of the calibration line

The latitude and longitude data is converted into x,y coordinates about an origin of 0,0 which is the location of the DGPS antenna inside the lifeboat when the lifeboat is attached to the davit lines and hoisted up (i.e. the start position). Conversion is achieved by subtracting the latitude and longitude of the origin from the latitude longitude fixes and converting to meters by the following algorithm:

Adjusted Latitude = Measured Latitude – Latitude of origin
Adjusted Longitude = Measured Longitude – Longitude of origin

y = (Adjusted Latitude * 111.317) * 1000
x = (Adjusted Longitude * 111.317 *
Cos(Measured Longitude * (pi / 180))) * -1000

Where Latitude of origin = 47.56096375
Longitude of origin = 52.70095969

The counter values are converted to rotations per second by taking the difference in measured counts and dividing by the difference in reference counts.

LifeboatCal writes the results of the calculations to a disc file. The calibrated data file may be decimated as well. In this case every x^{th} record is written, where x is the decimation factor chosen by the operator. The calibrated file may be read into Excel simply by double-clicking it from the file explorer.

ShorebaseLogger

The program ShorebaseLogger runs on the shore platform computer system. It is used to acquire data from analog channels. ShorebaseLogger provides a graphical user-interface that enables the operator to control acquisition. It was written in Microsoft Visual Basic 6.0, and tested for Windows 2000. The ShorebaseLogger program uses a programming interface from IOTech to issue commands and receive data from an onboard DaqBoard 2000.

The analog data sampling rate is hard coded at 100 samples per second for each of 16 analog channels, for an aggregate analog channel sampling rate of 1600 samples per second. Raw data counts from the Daqboard are recorded. The values are 16 bit unsigned integers where 0 corresponds to bottom of scale and 65535 corresponds to full scale. Data is post calibrated and changed to physical units by the ShorebaseCal program.

ShorebaseLogger writes the most recent buffers of data to disc at 1/10 of the sampling rate. The data is written in ASCII format, delimited by commas and spaces to enable the file to be easily read by programs such as Microsoft Excel.

The ShorebaseLogger program is operated in the same manner as the LifeboatLogger program.

ShorebaseCal

The program ShorebaseCal is used to calibrate and decimate the raw data that was recorded by the ShorebaseLogger program. ShorebaseCal serves two purposes: it calibrates the raw data and converts it to physical units; and it may also be used to decimate the data so that the large files may be viewed in near real-time via Excel. It produces calibrated data files in ASCII comma-space delimited (.CSV) format.

ShorebaseCal requires that the calibration constants be worked out at the beginning of the test program, and saved in an Excel spreadsheet in comma-space delimited format. The spreadsheet file will contain the slope and offset of the linear fit for each column of analog data.

Internally, the data is first converted from counts to units of volts by the following formula:

Volts = (Counts – 32767.5) * 0.00030518

Where Counts = 0 to 65535

Volts = -10 to +10

The calibration is then applied by the formula: y = m(x) + b

Where y = the physical quantity in the desired units

m = the slope of the calibration line

x = the analog value converted to volts

b = the offset of the calibration line

ShorebaseCal writes the results of the calculations to a disc file. The calibrated data file may be decimated as well. In this case every x^{th} record is written, where x is the decimation factor chosen by the operator. The calibrated file may be read into Excel simply by double-clicking it from the file explorer.

The ShorebaseCal program is operated in the same manner as the LifeboatCal program.

Time Synchronization

When precise time synchronization between computers is necessary, the easiest solution is to digitize a signal that is common to each acquisition computer. This is done by feeding a known signal, like a sine wave, to a channel on each acquisition computer. Each acquisition computer captures the common signal, and thus this signal will appear in all the datasets. The datasets may be synchronized by aligning this signal. In this experiment it is not possible to physically connect both acquisition computers to a common signal, without using a radio signal of some kind. Since a wireless network link exists, and very precise synchronization was not needed, time synchronization of the PC clocks using Tardis was chosen as an alternative.

Tardis software is installed on both the shore computer and the lifeboat computer. The shore computer is configured as the master and the lifeboat is configured as a slave. Periodically, Tardis on the lifeboat computer synchronizes the lifeboat computer clock by requesting a time

synchronization message from Tardis on the shore platform computer. Tardis on the lifeboat will therefore periodically jar the clock into synchronization with the shore computer clock. The real-world time is not very important in this case, but the operator will verify that the clock on the shore computer is reasonably correct.

Tardis uses a protocol that is statistical in nature. The level of synchronization is dependent on the speed of the network and the volume of network traffic, which may vary at any given instance. Additionally, over a wireless network there may be noise present which may affect the speed of data transfer. Tardis works by "jarring" the clocks into synchronization. Since the clock crystal on any given PC is notoriously variable, the instant after the clocks have been jarred they immediately begin to drift apart again. It is therefore not possible to perfectly synchronize the data by this method.

The assumption in the design of this acquisition system is that the pacer clock in the DaqBoard is more accurate than the PC's clock, and therefore the pacer clock may be trusted to give precise intervals, of 1/100 seconds in our case. The date-time stamps in the data files, synchronized by Tardis, may be used to synchronize the data between the two computers, to within approximately 1.5 seconds. If more precise synchronization is needed, it can only be accomplished by manually examining the data traces, with knowledge of how the events that occur during a given run must relate to the data trace. In other words, a peak or valley in the data on the shore computer may be visually correlated to a peak or valley in the data on the lifeboat computer, by knowing the real-world event that it represents.

Appendix D

TEMPSC Ballast System Description

The ballast system was developed to be suitable for use in the field-testing of lifeboats and so portability, flexibility of configuration and functionality were significant concerns. A water ballast system was selected over solid ballast (such as sand bags) to simplify the issue of de-ballasting should testing be attempted in a seaway. Rigid water ballast tanks were considered but were thought to be difficult to arrange and secure inside the lifeboat. Similarly, rigid ballast tanks, although easy to fill, would require siphon tubes or complex piping connected to tank bottoms to permit de-ballasting. Flexible water tanks were therefore selected and plumbed to a simple manifold that would allow the tanks to be filled and emptied. The tanks would be easy to position in the empty condition, would "inflate" upon filling and then deflate again as they were pumped dry.

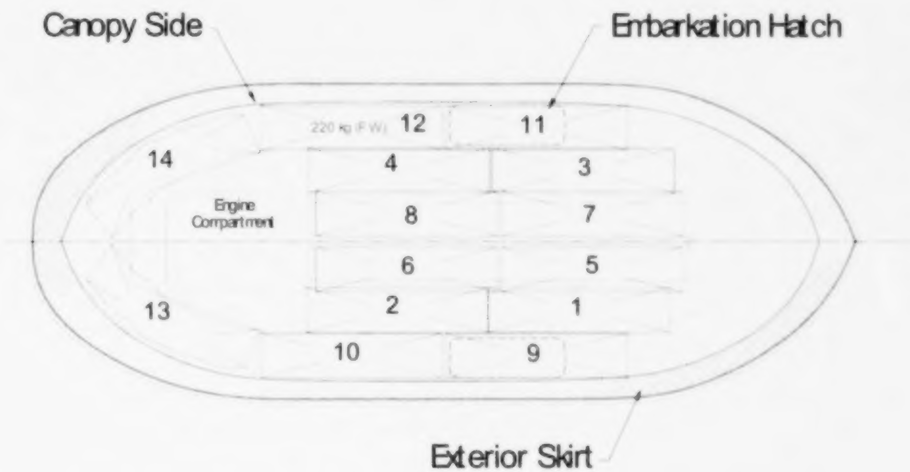


Figure D1: Lifeboat ballast tank arrangement (not to scale)

Vetus flexible water tanks were chosen for their size, price and availability. Their 220 litre rectangular tank was chosen as most suitable for positioning on the passenger seating inside the lifeboat. After testing different configurations, the arrangement shown in figure D1 was developed. This configuration used 14 "bags" organized into 3 zones. Each zone was provided with a separate manifold as smaller and less complex manifolds simplified the setup and disassembly of the ballast system. The first zone consisted of 4 bags (#s 1, 2, 3 & 4) that were positioned with 2 bags in each of the Port and Starboard "foot wells" below the passenger seating. These four bags formed a lower "tier" and plywood was then positioned across the passenger seat bottoms above these bags to support an upper tier. The upper tier was organized into two zones and the smaller of these consisted of 2 bags (#s 13 & 14), 1 on each of the port and starboard quarter seats. The 8 remaining bags (#s 5, 6, 7, 8, 9, 10, 11 & 12) formed the third zone with 4 bags on each side of the centerline partition. Of these 4 bags on each of the port and starboard sides, 2 were on the inboard

seating surfaces and 2 were on the outboard seating surfaces. The foot wells and seating surfaces are shown in the figure D2.

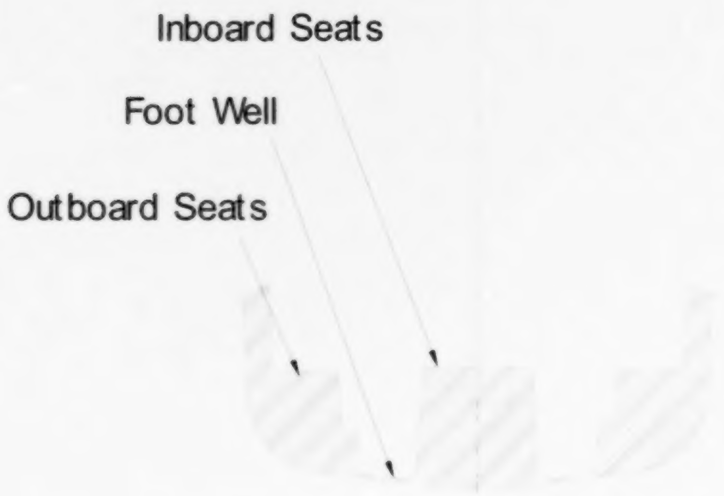


Figure D2: Seating surfaces and foot well positions for ballast tank placement (not to scale)

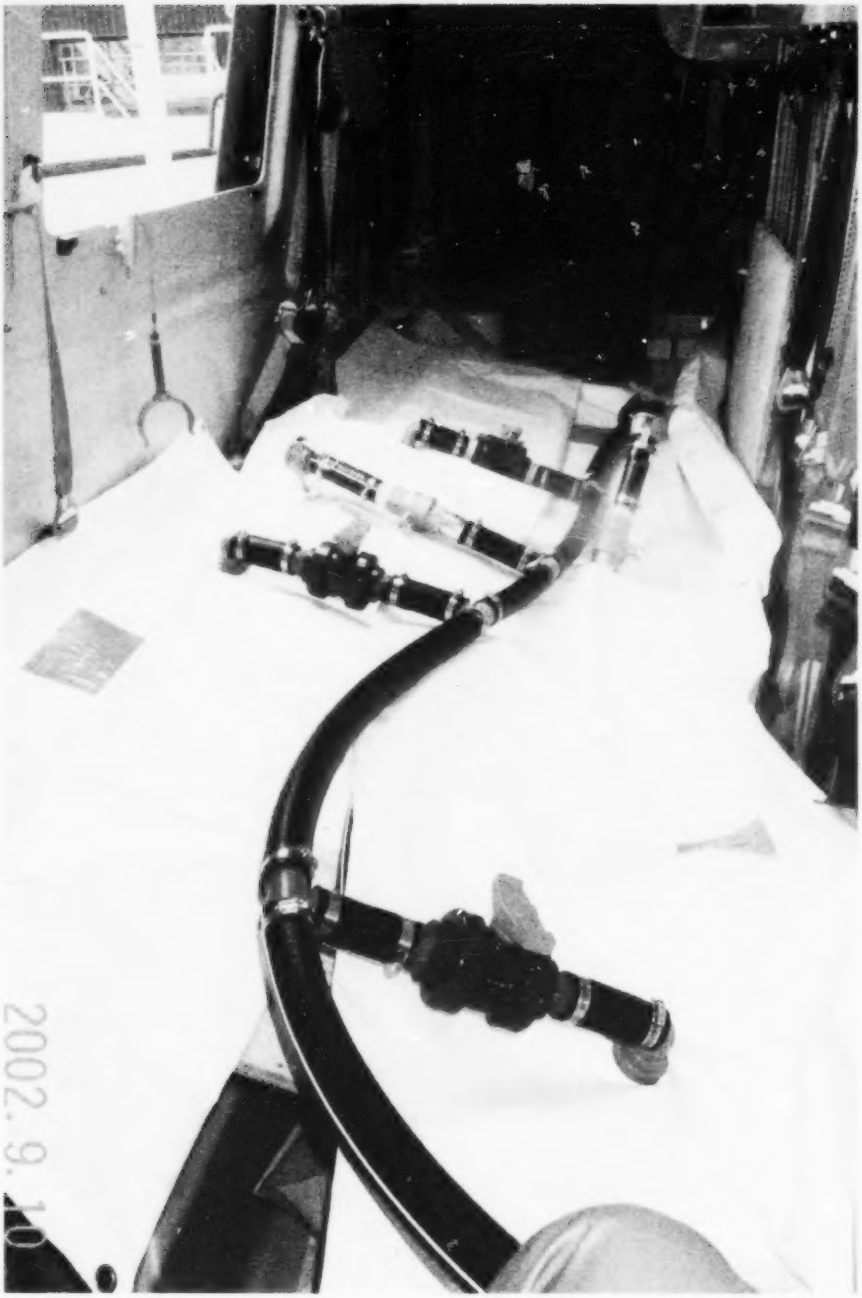
The manifold for each of the three zones was fabricated from 1.5 in dia “flexible” plastic pipe. This pipe was rigid enough to allow its use as a suction line during de-ballasting operations. Plastic “tee” and “elbow” fittings were used with hose clamps to assemble suitable manifold configurations with each ballast bag attached to a separate branch line. Each of these branch lines was then fitted with a ball valve so that individual ballast bags could be isolated to allow full control of filling and emptying. An additional branch line was fitted to each of the three manifolds to provide a connection for filling and emptying. These fill lines were also fitted with a ball valve and were terminated in a cam lock fitting to permit easy attachment of filling and suction lines.

When ballasting the boat, the bags were filled, zone-by-zone, starting with the lowest zones and working up. The foot well bags were filled first, followed by the inboard bags in the upper tier, the outboard bags in the upper tier and finishing with the bags on the quarter seats. Fill water was supplied through a 1.5 in hose flowing fresh water from a municipal line. Using the cam lock fittings, the fill line was moved from manifold to manifold as necessary while the ball valves were used to control water flow. The amount of ballast water used was monitored with an in-line flow meter.

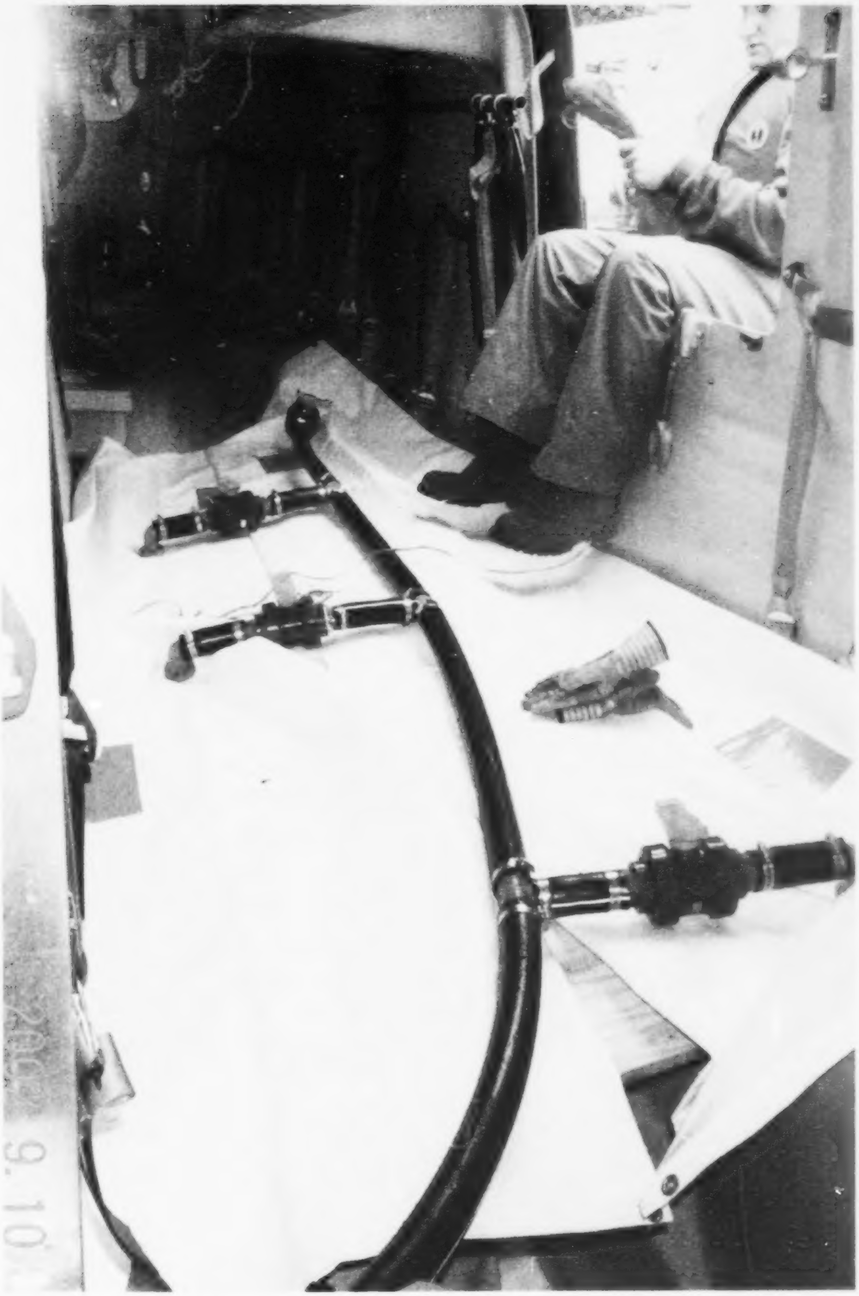
The ballast bags were emptied in the reverse order using a Kodiak Power Equipment pump, model PWP2CH4C, powered by a 4.0 hp Honda gasoline engine and rated to pump 600 L/min. The pump was advertised as self-priming and suction lift was rated at 6 metres. However, in testing, the pump did not always self-prime or maintain prime. This initial difficulty was attributed to the air that was captive at various points in the bags and lines of the ballast system and to occasional air leaks around fittings. Connecting a garden hose to the priming port of the pump and flowing water into this port continuously during pumping operations ended the priming difficulty.

For operation in the field, water for ballast system filling could be supplied from ship/installation mains or the portable pump could also be used for this purpose. During de-ballasting operation in the field, pump prime could be assisted by using a 12 volt submersible or bilge pump powered from the lifeboat or a work boat.

Selected photographs of the water ballast system are shown below.

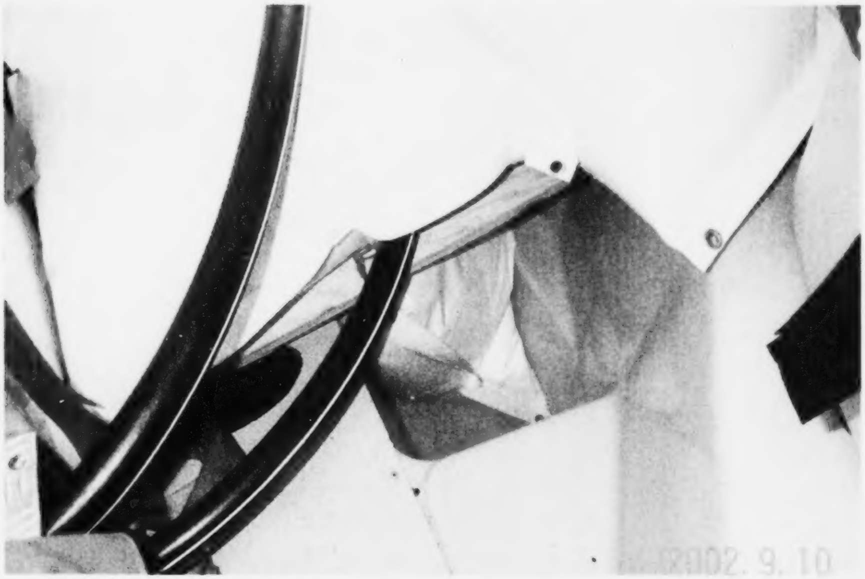


Ballast bags, manifolds and filling/de-watering connection on Starboard side of lifeboat. Corner of bag in lower tier can be seen in foreground under manifold piping.



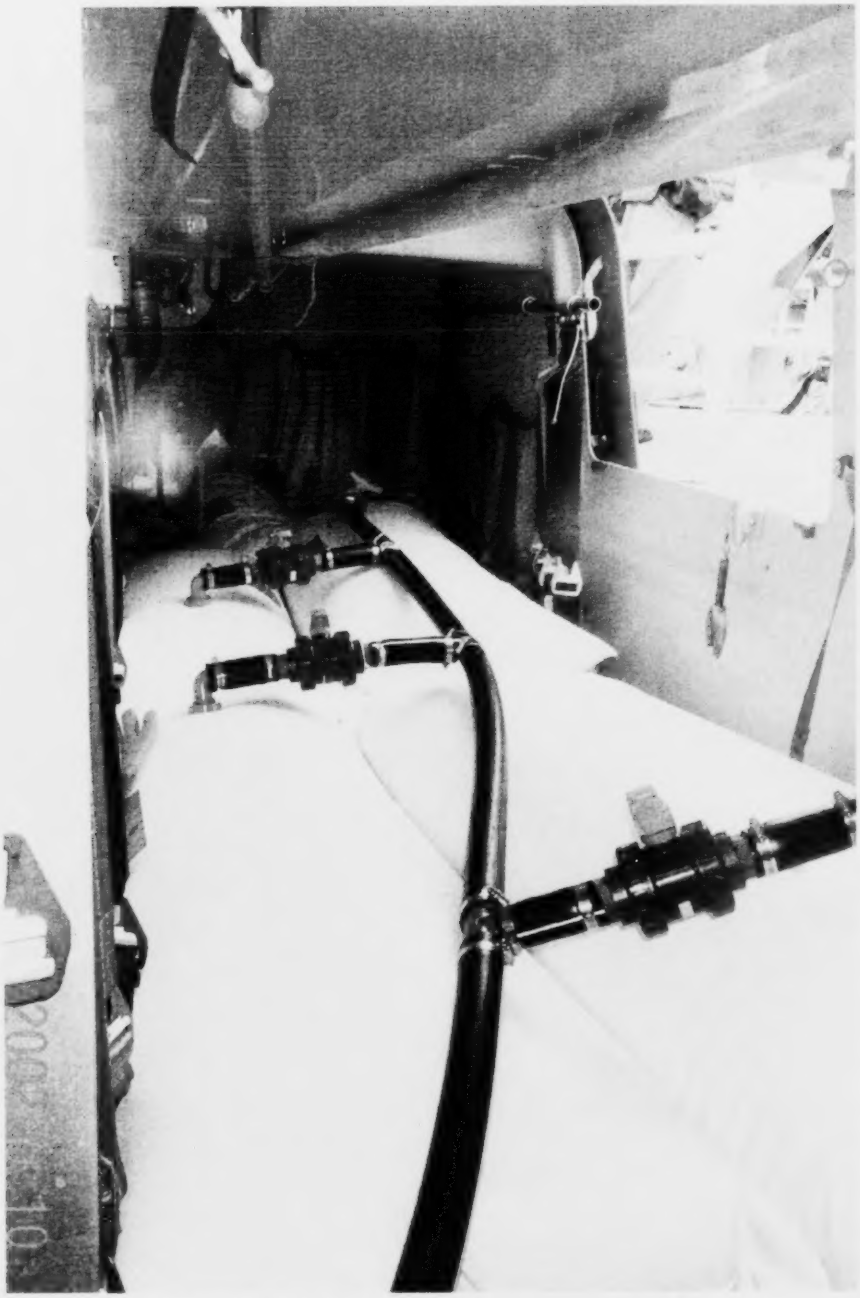
Ballast bags and manifolds on Port side of lifeboat

Lower tier ballast bags, Starboard side

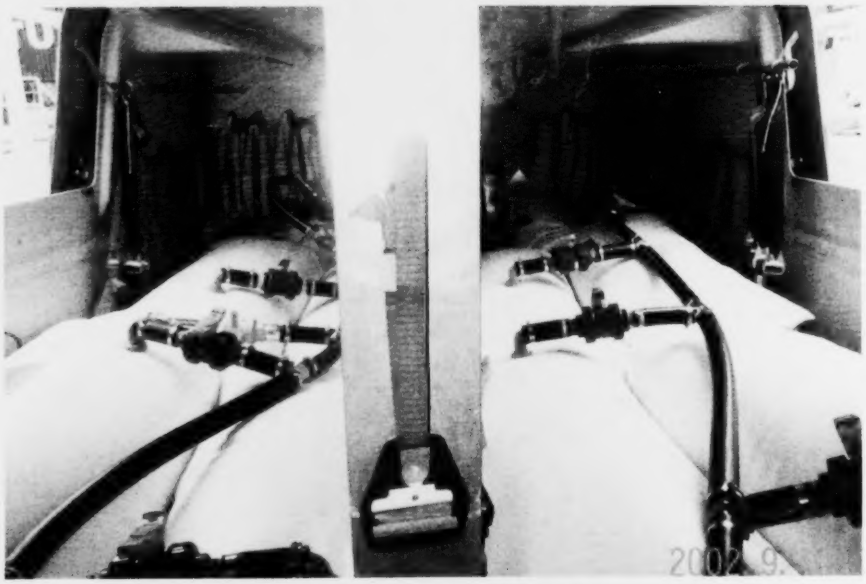


Lower tier ballast bags filled, Port side

Ballast bags filled, Starboard side

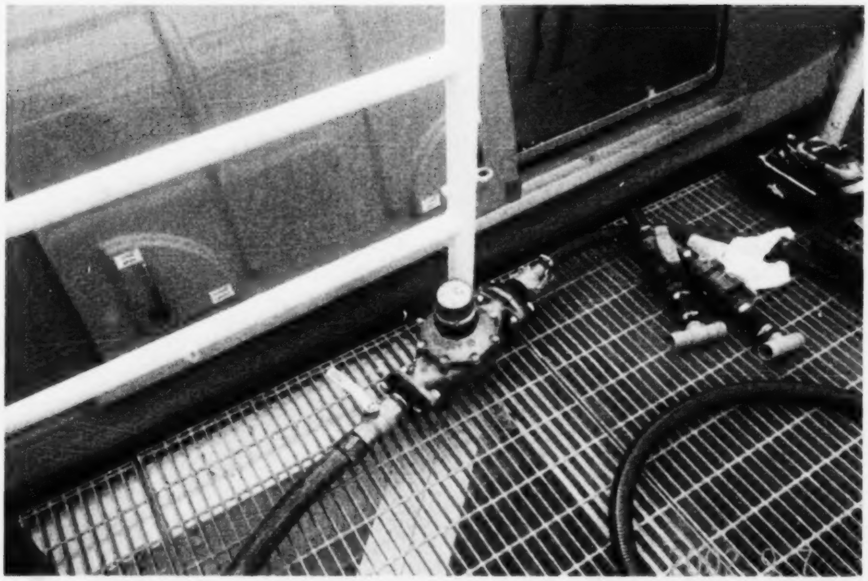


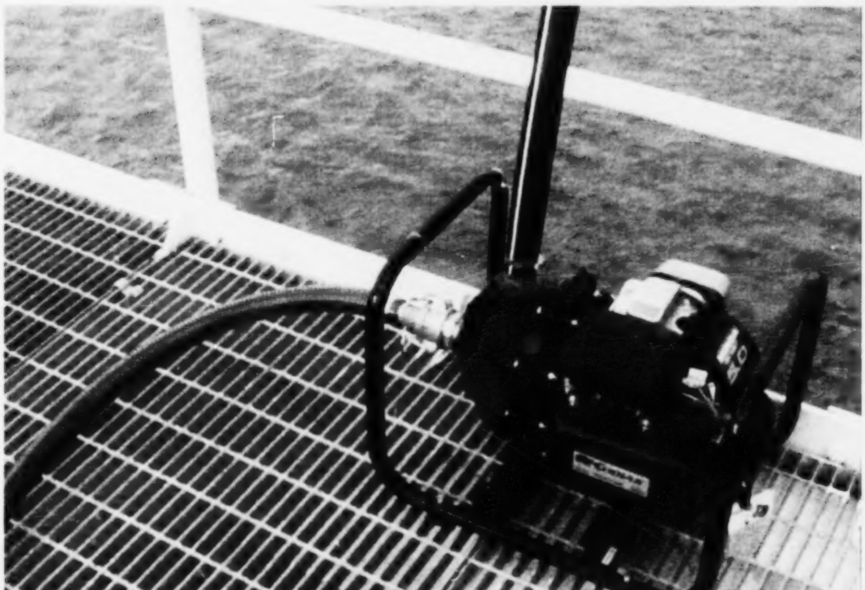
Ballast bags filled, Port side



Lifeboat in ballasted condition

Typical connection to manifold for filling and de-watering ballast bags


Fire hose, shut-off valve and meter used to control water ballast volume


De-watering pump

Post-launch de-watering of lifeboat in preparation for hoisting

Appendix E

Heave, Pitch and Roll Decay Data

```
Output from GEDAP program damped_sine_fit run on
heave decay data from H_H_001

                                                17:19:36   14-NOV-03
-----------------------------------------------------------------------
   GEDAP Data File: "DISK$PROJECT:[PJ00874.FULL_SCALE]H_H_SIN.001;5"
-----------------------------------------------------------------------

   Type V1:    The file contains a single real data vector Y(x)
               where Y = Zacc (g)
               and   x = Time (seconds).

               N  = 512
               DX = 0.00913894 seconds
               X1 = 374.530 seconds

               IFORM   = 2   (Real)

   The file was generated by program HEADER, Version  1.60


 B-Header Integer Parameters:   (None)


 B-Header Real*4 Parameters:

   SIN_AMPLITUDE  0.370879
   SIN_FREQUENCY  0.467544
   SIN_GAMMA      0.197134
   SIN_MEAN       -1.00981
   SIN_PHASE_DEG  -138.657

   SIN_RMS_ERROR  0.0268237
   SIN_TAU        1.72678

 B-Header Real*8 Parameters:   (None)


 B-Header Character Parameters:

   CLIENT           IOT Marine Safety Team
   DAS_START_DATE   16-Sep-2002
   DAS_START_TIME   15:20:00
   DATA_CHAN_1      Time
   DATA_CHAN_2      Zacc

   DATA_X           Time
   DATA_Y           Zacc
   PROJECT_PHASE    Phase 2
   PROJECT_TITLE    Full Scale
   TEST_NUMBER      H_H_001

   UNITS_CHAN_1     seconds
   UNITS_CHAN_2     g
   UNITS_X          seconds
   UNITS_Y          g
```

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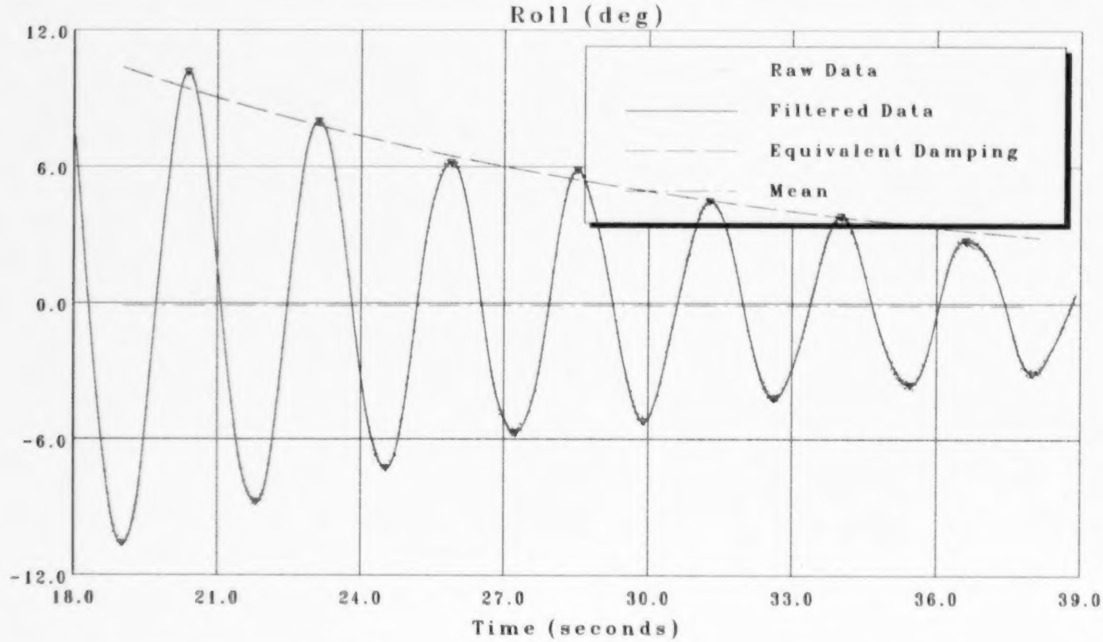
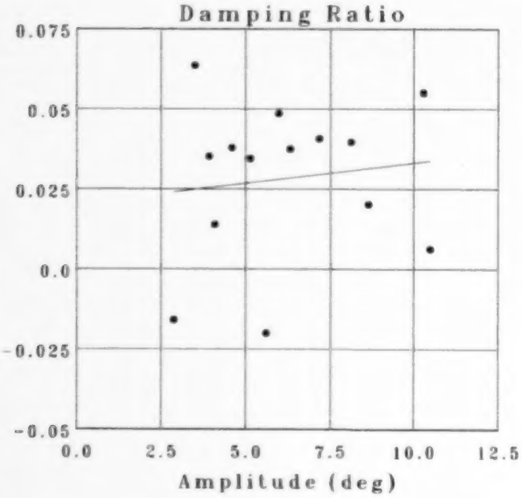
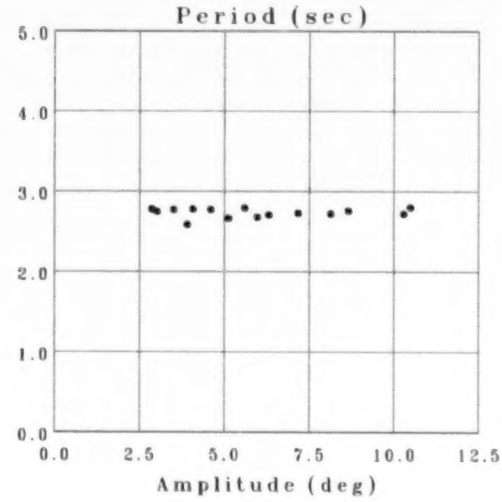
Full Scale
Phase 2

Analyzed: 14-NOV-2003 15:26:01
Acquired: 16-Sep-2002 16:50:00







MEAN

Offset = -0.1134 deg
Period = 2.733 sec

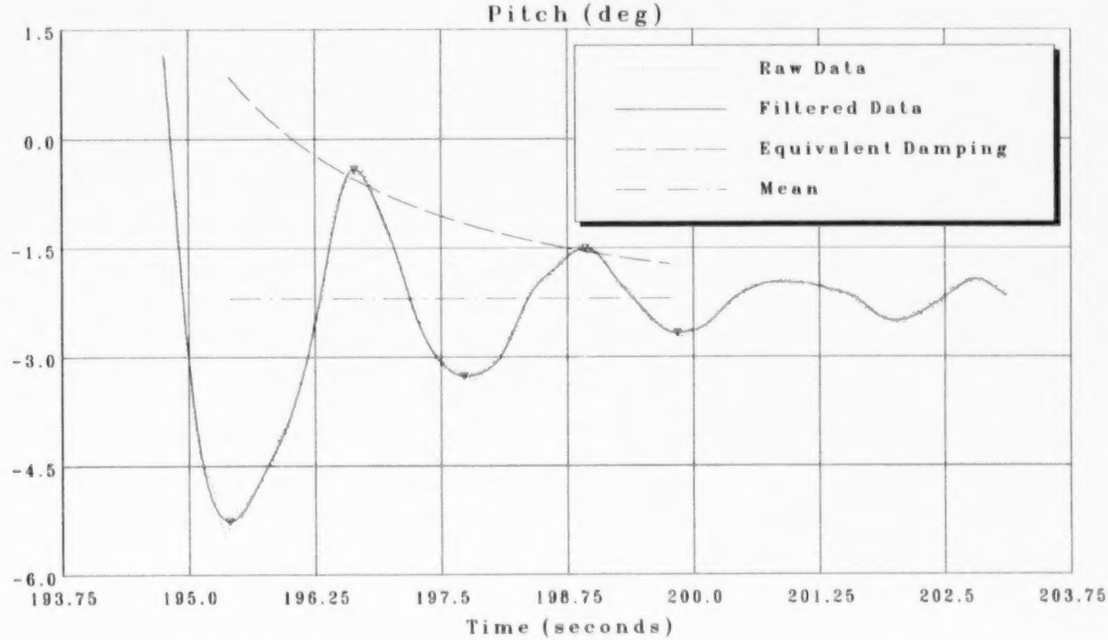
DAMPING

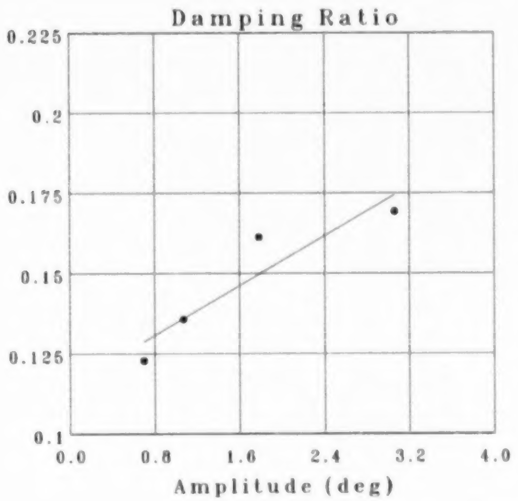
Linear = 0.02838
Equivalent B1 = 0.02057
Equivalent B2 = 0.001262

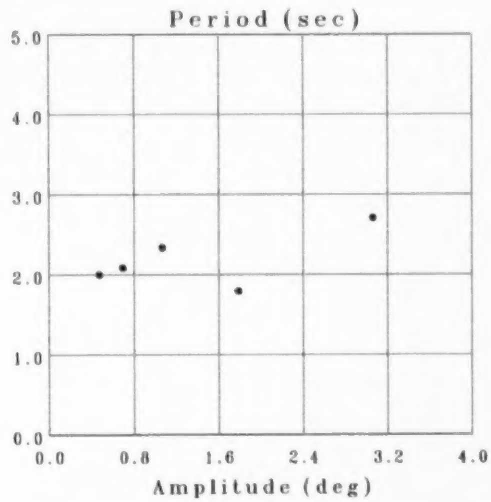
IOT Marine Safety Team

Full Scale
Phase 2

Analyzed: 14-NOV-2003 15:29:43
Acquired: 16-Sep-2002 16:41:00







MEAN	DAMPING
Offset = -2.199 deg	Linear = 0.1472
Period = 2.182 sec	Equivalent B1 = 0.1153
	Equivalent B2 = 0.01934

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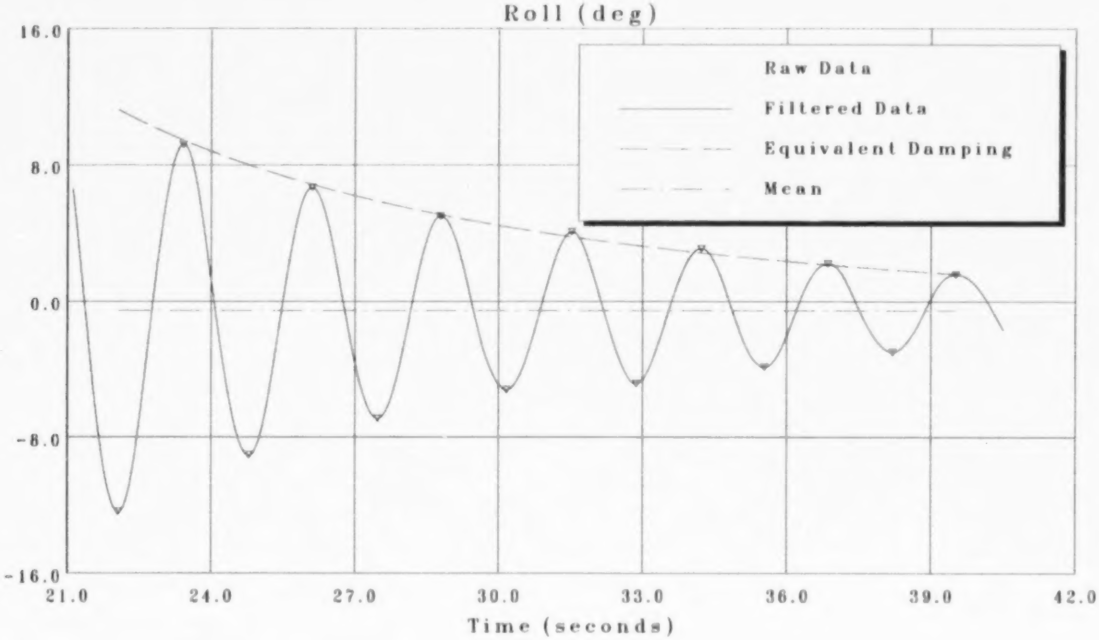
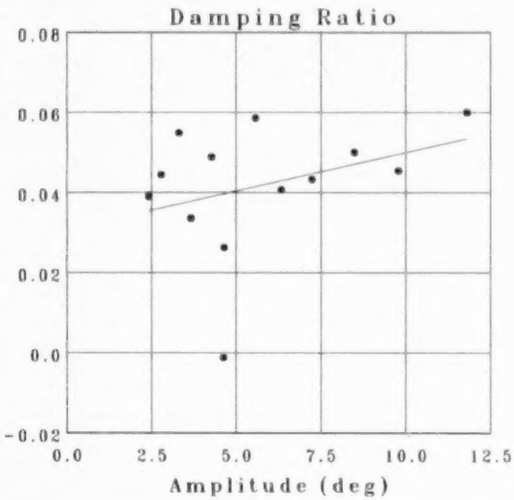
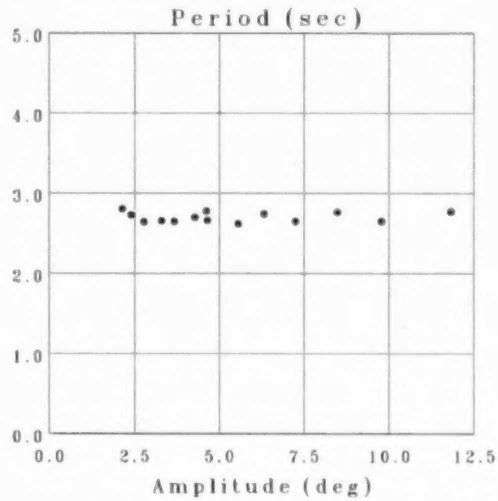
Pitch
H_P_001





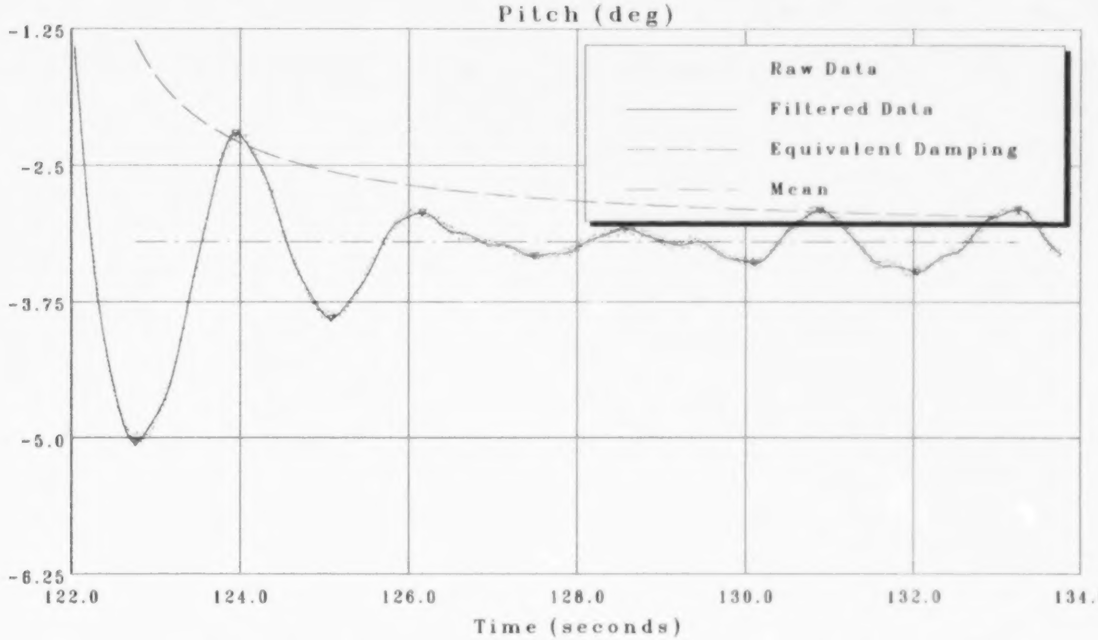


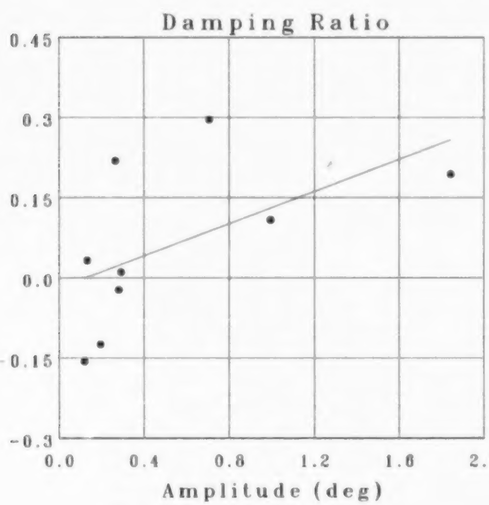
MEAN	DAMPING
Offset = -0.5640 deg	Linear = 0.04184
Period = 2.701 sec	Equivalent B1 = 0.03078
	Equivalent B2 = 0.001918

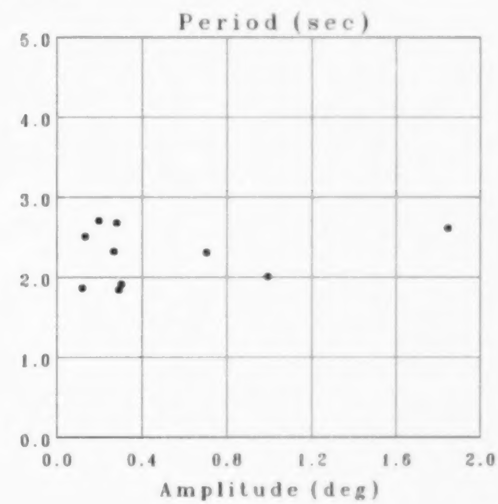
IOT Marine Safety Team

Full Scale
Phase 2

Analyzed: 14-NOV-2003 15:33:37
Acquired: 16-Sep-2002 19:55:00







MEAN	DAMPING
Offset = -3.199 deg	Linear = 0.06171
Period = 2.276 sec	Equivalent B1 = -0.01904
	Equivalent B2 = 0.1507

National Research Council Canada
Institute for Marine Dynamics

Pitch
L_P_001

Roll (deg)

Offset	Average Period	Linear Damping Coefficient	Equivalent Damping Slope	Equivalent Damping Offset
-0.1134	2.7326	0.02838	0.00126	0.02057

Roll (deg)

Amplitude	ABS(Amplitude-Offset)	Damping Ratio	Period
-10.6079	10.4944	0.00625	2.8019
10.1769	10.2903	0.05505	2.7194
-8.7673	8.6539	0.02024	2.7569
8.0072	8.1206	0.03971	2.7187
-7.2808	7.1674	0.04083	2.7282
6.1904	6.3038	0.03748	2.7055
-5.7165	5.6031	-0.02004	2.7902
5.8539	5.9673	0.04857	2.6767
-5.2354	5.1220	0.03444	2.6619
4.4830	4.5964	0.03796	2.7718
-4.1928	4.0793	0.01386	2.7761
3.7920	3.9054	0.03528	2.5861
-3.6089	3.4954	0.06357	2.7696
2.7481	2.8615	-0.01588	2.7783
-3.1213	3.0078		2.7482

Pitch (deg)

Offset	Average Period	Linear Damping Coefficient	Equivalent Damping Slope	Equivalent Damping Offset
-2.1987	2.1820	0.14720	0.01934	0.11527

Pitch (deg)

Amplitude	ABS(Amplitude-Offset)	Damping Ratio	Period
-5.2573	3.0586	0.16920	2.7073
-0.4150	1.7836	0.16119	1.7879
-3.2664	1.0677	0.13568	2.3331
-1.5042	0.6944	0.12275	2.0858
-2.6695	0.4708		1.9959

Roll (deg)

Offset	Average Period	Linear Damping Coefficient	Equivalent Damping Slope	Equivalent Damping Offset
-0.5640	2.7015	0.04184	0.00192	0.03078

Roll (deg)

Amplitude	ABS(Amplitude-Offset)	Damping Ratio	Period
-12.3799	11.8158	0.06006	2.7733
9.2168	9.7808	0.04537	2.6531
-9.0442	8.4802	0.05006	2.7651
6.6806	7.2447	0.04335	2.6468
-6.8854	6.3214	0.04066	2.7404
4.9988	5.5628	0.05867	2.6233
-5.1889	4.6249	-0.00126	2.7759
4.0791	4.6432	0.02626	2.6639
-4.8394	4.2754	0.04886	2.6976
3.1023	3.6663	0.03361	2.6496
-3.8627	3.2986	0.05483	2.6537
2.2119	2.7759	0.04446	2.6434
-2.9778	2.4137	0.03894	2.7269
1.5716	2.1356		2.8079

Pitch (deg)

Offset	Average Period	Linear Damping Coefficient	Equivalent Damping Slope	Equivalent Damping Offset
-3.1988	2.2759	0.06171	0.15068	-0.01904

Pitch (deg)

Amplitude	ABS(Amplitude-Offset)	Damping Ratio	Period
-5.0437	1.8449	0.19375	2.6153
-2.2068	0.9920	0.10833	2.0079
-3.9032	0.7044	0.29648	2.3054
-2.9332	0.2656	0.21893	2.3232
-3.3300	0.1312	0.03220	2.5042
-3.0802	0.1186	-0.15690	1.8652
-3.3942	0.1953	-0.12505	2.7043
-2.9086	0.2902	0.01050	1.8433
-3.4796	0.2808	-0.02287	2.6781
-2.8971	0.3017		1.9117

Appendix F

Test Plan and Trial Filenames

FILENAME		DESCRIPTION
BOAT SIDE	SHORE SIDE	
FSA_B_1P1P5_001	FSA_S_1P1P5_001	FULL-SCALE SERIES A, HEAVY, POSITION 1, 1.5 M, RUN 1
FSA_B_2P4P5_001	FSA_S_2P4P5_001	FULL-SCALE SERIES A, HEAVY, POSITION 2, 3.0 M, RUN 1
FSA_B_3P7P0_001	FSA_S_3P7P0_001	FULL-SCALE SERIES A, HEAVY, POSITION 3, 7.0 M, RUN 1
FSA_B_1P1P5_002	FSA_S_1P1P5_002	FULL-SCALE SERIES A, HEAVY, POSITION 1, 1.5 M, RUN 2
FSA_B_2P4P5_002	FSA_S_2P4P5_002	FULL-SCALE SERIES A, HEAVY, POSITION 2, 3.0 M, RUN 2
FSA_B_3P7P0_002	FSA_S_3P7P0_002	FULL-SCALE SERIES A, HEAVY, POSITION 3, 7.0 M, RUN 2
FSA_B_1P1P5_003	FSA_S_1P1P5_003	FULL-SCALE SERIES A, HEAVY, POSITION 1, 1.5 M, RUN 3
FSA_B_2P4P5_003	FSA_S_2P4P5_003	FULL-SCALE SERIES A, HEAVY, POSITION 2, 3.0 M, RUN 3
FSA_B_3P7P0_003	FSA_S_3P7P0_003	FULL-SCALE SERIES A, HEAVY, POSITION 3, 7.0 M, RUN 3
FSA_B_4PW_003	FSA_S_4PW_003	FULL-SCALE SERIES A, HEAVY, POSITION 4, WATER LEVEL, RUN 3
FSA_B_L_1P1P5_001	FSA_S_L_1P1P5_001	FULL-SCALE SERIES A, LIGHT, POSITION 1, 1.5 M, RUN 1
FSA_B_L_2P4P5_001	FSA_S_L_2P4P5_001	FULL-SCALE SERIES A, LIGHT, POSITION 2, 3.0 M, RUN 1
FSA_B_L_7P3P0_001	FSA_S_L_7P3P0_001	FULL-SCALE SERIES A, LIGHT, POSITION 3, 7.0 M, RUN 1
FSA_B_L_4PW_001	FSA_S_L_4PW_001	FULL-SCALE SERIES A, LIGHT, POSITION 4, WATER LEVEL, RUN 1
FSB_B_DP_001	FSB_S_DP_001	FULL-SCALE SERIES B, HEAVY, NO FLEX BOOM, POWER, RUN 1
FSB_B_FBP_001	FSB_S_FBP_001	FULL-SCALE SERIES B, HEAVY, FLEX BOOM, POWER, RUN 1
FSB_B_FB_NP_001	FSB_S_FB_NP_001	FULL-SCALE SERIES B, HEAVY, FLEX BOOM, NO POWER, RUN 1
FSB_B_DP_L_001	FSB_S_DP_L_001	FULL-SCALE SERIES B, LIGHT, NO FLEX BOOM, POWER, RUN 1
FSB_B_FBP_L_001	FSB_S_FBP_L_001	FULL-SCALE SERIES B, LIGHT, FLEX BOOM, POWER, RUN 1
FSB_B_FB_NP_L_001	FSB_S_FB_NP_L_001	FULL-SCALE SERIES B, LIGHT, FLEX BOOM, NO POWER, RUN 1
FSC_B_AC_001	FSC_S_AC_001	FULL-SCALE SERIES C, HEAVY, ACCELERATION, RUN 1
FSC_B_AC_002	FSC_S_AC_002	FULL-SCALE SERIES C, HEAVY, ACCELERATION, RUN 2
FSC_B_AC_003	FSC_S_AC_003	FULL-SCALE SERIES C, HEAVY, ACCELERATION, RUN 3
FSC_B_AC_004	FSC_S_AC_004	FULL-SCALE SERIES C, HEAVY, ACCELERATION, RUN 4
FSC_B_L_AC_001	FSC_S_L_AC_001	FULL-SCALE SERIES C, LIGHT, ACCELERATION, RUN 1
FSC_B_L_AC_002	FSC_S_L_AC_002	FULL-SCALE SERIES C, LIGHT, ACCELERATION, RUN 2
FSD_B_BP_H_001	FSD_S_BP_H_001	FULL-SCALE SERIES D, HEAVY, BOLLARD PULL, RUN 1
FSD_B_BP_H_002	FSD_S_BP_H_002	FULL-SCALE SERIES D, HEAVY, BOLLARD PULL, RUN 2
FSD_B_BP_L_001	FSD_S_BP_L_001	FULL-SCALE SERIES D, LIGHT, BOLLARD PULL, RUN 1
FSD_B_BP_L_002	FSD_S_BP_L_002	FULL-SCALE SERIES D, LIGHT, BOLLARD PULL, RUN 2
FSE_B_H_IE_001	FSE_B_H_IE_001	FULL-SCALE SERIES E, HEAVY, INCLINING, RUN 1
FSE_B_L_IE_001	FSE_B_L_IE_001	FULL-SCALE SERIES E, LIGHT, INCLINING, RUN 1
FSF_B_H_H_001	FSF_S_H_H_001	FULL-SCALE SERIES F, HEAVY, DECAY, HEAVE, RUN 1
FSF_B_H_P_001	FSF_S_H_P_001	FULL-SCALE SERIES F, HEAVY, DECAY, PITCH, RUN 1
FSF_B_H_R_001	FSF_S_H_R_001	FULL-SCALE SERIES F, HEAVY, DECAY, ROLL, RUN 1
FSF_B_L_H_001	FSF_S_L_H_001	FULL-SCALE SERIES F, LIGHT, DECAY, HEAVE, RUN 1
FSF_B_L_P_001	FSF_S_L_P_001	FULL-SCALE SERIES F, LIGHT, DECAY, PITCH, RUN 1
FSF_B_L_R_001	FSF_S_L_R_001	FULL-SCALE SERIES F, LIGHT, DECAY, ROLL, RUN 1